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THIS Index, as well as the previous indexes, is arranged according to the topical classification of subjects. The original scheme for this method of indexing was published in the Journal for February, 1906. All articles which have appeared in the Journal since its initial issue can be located quickly by the use of the Ten-Year Index, (1904-1913), the Five-Year Index, (1914-1918), and the present Index, which covers the first three years of the fourth pentad.

Abbreviations: *T*—Number of Tables; *C*—Number of Curves; *D*—Number of Diagrams; *I*—Number of Illustrations; *W*—Number of Words; *QB*—Question Box; *EN*—Engineering Notes; *EH*—Industrial Applications of Electric Heaters; *OD*—Operating Data for Converting Substations; *ROD*—Railway Operating Data. (The numerals following *EN*, *EH*, *OD* and *ROD* are volume and page numbers.) The main headings and sub-divisions are as follows:—

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Lightning Arresters to Absorb Inductive Kick—QB, 1772.

Choke Coils QB, 1809.

Lightning Protection for Meters QB, 1825.

Testing Electrolyte for Impurities—QB, 1836.

Noise in Transformers Due to Charging—QB, 1888.

Choke Coil Effect of Armored Cable QB, 1967.

Choke Coil—QB, 1976.

Lightning Arrester Connections 2075.

Synchronizing Schemes

Synchronizing with Lamps—J. C. Group. D-2, I-4, W-1850. Vol. XVII, p. 536, Nov., '20.

Synchronizing with Synchronoscopes J. C. Group. D-13, W-2650. Vol. XVII, p. 567, Dec., '20.

Synchronizing Alternators—QB, 1850.

Synchronizing Two-Phase to Three-Phase Lines QB, 1951.

REGULATION AND CONTROL

Regulators

The Step Induction Regulator E. E. Lehr. C-1, D-4, I-7, W-2500. Vol. XVII, p. 510, Nov., '20.

Tie Line Application for Induction Feeder Regulators—C. R. Gilchrest. D-1, I-6, W-1000. Vol. XVII, p. 518, Nov., '20.

The Liquid Slip Regulator—Guy F. Scott. C-2, I-3, W-1250. Vol. XVIII. p. 87, Jan., '21.

Transformer Connections—QB, 1703.

Connection of Tirrill Regulator—QB, 1818.

Induction Regulator—QB, 1840.

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THE ELECTRIC JOURNAL

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Public Utility Economics

The street railway and electric light and power industries are beginning a new and distinct economic era. They have passed through perhaps as many different economic phases as there have been different scientific, mechanical and engineering periods in the industry. We can, however, secure an interesting viewpoint of the present development of what may be called the public economics of public utilities without referring to any more remote period of time than the few years just before the world war. At that time regulation of public utilities, on the sole theory of restraining or curbing private enterprise, had reached its full development and it had carried with it some results which contained both good and bad elements, although the final outcome was bad, as was inevitable.

One of the good aspects was that, by reason of the public belief in the "naturally" huge profits of the industry and in the necessity for a check upon them by the means of repressive regulation, there was created an atmosphere of financial security and opportunity which was attractive to investors, and which made possible the development of these properties fast enough to keep pace with the needs of the people.

It is true that during the latter part of this repressive period the managers and operators of public utilities, and particularly street railways, saw danger ahead and loudly called for a new dispensation. They demanded, in effect, a removal of their case from the criminal court to a court of equity.

The apparent result of these protests was nothing. Even the growing number of receiverships of street railway companies had very little effect upon the public mind because they were told by advocates of one kind and another that each individual case stood by itself and was the result of high finance or bad management, or something else peculiar to the individual company itself. That there was anything fundamentally wrong with repressive regulation was vigorously denied.

Then came the war and it was evident that all enterprises which were under governmental regulation stood on the verge of bankruptcy. It was a nation-wide condition of all regulated public utilities and at a time when unregulated business was enjoying high prosperity.

Perhaps this situation, standing alone, would not have moved a reform, but the additional fact that the Nation had to finance a great war and that it would have been impossible to do so, in the face of a national bankruptcy of railroads and other public utilities, led to the inauguration of the present era. It is an accepted theory now that one of the duties of regulatory bodies (and in some cases it is made mandatory by law) is to consider the financial needs of public utility companies in a positive manner as distinguished from the former negative system.

There has arisen under this new dispensation (and quite naturally) a method of measuring the compensation to the private capital and enterprise engaged in the industries, called the cost of service system, which however comprises many different plans.

The idea of Cost of Service is not an entirely new one, but its general acceptance gives it a new position of importance; it has almost reached the point of becoming the slogan for the settlement of all public utility questions. Like most condensed expressions, "Cost of Service" may mean many things to many people; and, unless it can be defined so thoroughly and widely that the public will understand what it must mean if it is to be successfully applied to private ownership and operation of public utilities, there is danger in it.

The public ought to realize that private enterprise will not be attracted to any private industry in which the door is closed to all reward beyond the mere interest on the money invested, and that a successful "Cost of Service" plan must include some probability of profit over and above mere interest.

There is little doubt that the public generally does not so understand "Cost of Service" at the present time, and it will be well to be sure that the minds of the parties in interest, viz. the public and owners and operators of utilities, have met before encouraging the further use of the expression as a slogan.

Profit may be provided for in a variety of ways, but permitting the possibility of its attainment is the only way to secure the energy and economy of private ownership and operation, and I suppose the new school of regulation is designed to secure and encourage that very thing, for I believe the public has endorsed private ownership and operation.

In order that present day regulatory methods may be successful, it will also be necessary that the public utilities co-operate with the regulatory authorities in every proper way, because no one can predict just what the public reaction will be, as the working out of the future public utility problems proceeds, and as the commissioners exercise their power and duty to raise rates as well as to reduce them. It has been very reassuring

so far, and the public has accepted the decisions of their commissioners with a readiness which shows a complete confidence in them; and, speaking generally, there is no indication of any incipient dissatisfaction.

However, that is no reason for a relaxation of the efforts of public utilities to co-operate in all possible ways, and there is one policy which will be helpful in the situation; one, fortunately, that will also be of direct benefit to the utilities themselves. I refer to the successful efforts which are now being made in several sections of the country to sell the common stock of utilities to local investors in small blocks. This plan is almost ideal. In the first place, it tends to that healthy condition where the local people own the equity in their own utility. They have an investment in a property which they see and use every day. It is almost an ideal investment because the people themselves by their own actions assist in insuring the stability of their own investment, and they need never sustain losses except by their own action or by that of their own representatives in public office.

The "foreign" security owner tends to become simply a lender of money, having an investment secured by mortgage, and he will be content with a lower rate of return because a substantial local ownership of stock is an insurance of safety to the investor in bonds and that fact must improve the credit of a utility.

The widespread local ownership of common stock of a public utility ought also to be the strongest pillar of support to regulatory bodies in their new role, which is bound to be a more difficult part to play than their old one. Therefore, I regard the vigorous extension of the policy of local sale of common stock of public utilities to be an indispensable adjunct to the present system of public regulation in that it will tend to protect it against a possible reaction of the public mind. I regard this new era as a great step in advance of anything that has heretofore existed in the field of public regulation of public utilities, and what I have said is meant only to suggest a point of danger which we should have in mind.

As previously stated, I believe private ownership and operation have been endorsed by the people and future administration of utilities will be based upon that policy unless for one reason or another regulation falls into such an impassé with natural business or economic laws, that government ownership will be the only solution. There is, however, less likelihood of such an outcome now than ever before in the history of public utilities, at least since they have become a vital factor in the daily life of the people.

Sound economics have not been preached for years without effect. The outlook is an encouraging one and I look for the early restoration of the credit of public utilities under a method of regulation which will in time place their securities next to government obligations.

G. E. Tripp

A Perspective View

About sixty million of our population live under electric wires. Of this great number of people, every man, woman and child requires something over one kilowatt-hour per day to take care of his or her needs and comforts. From the time we rise in the morning until we retire at night we use electric current. We light with it, we heat with it, we are transported by it and we operate our factories with it. In a myriad of ways it ministers to our necessary uses. It is one of the principal elements of our present civilization. Obvious as this may be, it is a good way to start thinking about the electrical business, particularly in relation to its future prospects. The electrical industry embraces the manufacture and use of machinery, apparatus, devices and materials for the generation, transmission and absorption of electrical energy. A large number of plants are engaged in these manufactures. Many thousand of central stations generate and distribute the power to large communities. Isolated plants exist in great number in factories, in office buildings, in hotels and the like, although the drift of power supply is inevitably of economic necessity toward the central station.

Viewing the electrical business in its numerous aspects it would be hard to find any other industry which is more sound. It is sound from the investors standpoint because it is based on a public need growing all the time, and it is generally well financed. It is sound from a public standpoint, as it gives more for the money than anything else which is manufactured and sold. It furthermore is not a profiteering business. In all its branches the profits are very moderate. It is sound from a national standpoint because it offers the greatest possible means of conserving our national resources, building up new communities and making new enterprises possible. It possesses the economic advantage of a steady growth which can be fairly predicted, permitting of a reasonable parity of facilities and demand. Finally, it is a business of great moral soundness, where the work is constructive, the results genuine in public benefit, where good hearts cheerfully give the best they have. Its men are high grade and so are its methods.

For the past fifteen or twenty years the consumption of electrical energy per capita has doubled about every five years. This rapid growth has necessitated much new financing, requiring for the utility companies somewhere between fifty and one hundred dollars of new capital for each person that is added to their population served. With high rates for new money, with operating and construction costs mounting skyward, and with very little increase in their service rates, their burden has been very heavy. But their condition is improving. Rate increases, though small, have brought relief. Operating costs show a lowering tendency, and the utility securities are gaining in favor. The great thing about the electrical industry is the continual improvements in the art which have made the cost of elec-

tric power lower and lower, while most other necessities have become dearer. The inventor, the engineer, the mechanician, the scientist have all been able to frustrate the economic laws which in most commodities have robbed the dollar of its vitality. Today a pound of coal burned at the central station will deliver to your house something like 425 candle-power hours. Twenty years ago it was about 85. Each unit of apparatus in the long train of transformations between that pound of coal and your electric light has experienced tremendous improvement, and so have the methods of their use.

If Jonathan Swift's Brobdingnagian was right, that a man who grew two blades of grass where one had grown before deserved more of mankind than the whole race of politicians put together, what would he say of our engineering brethren who have multiplied so many times the service to our communities of the energy in our coal and in our rivers and streams. And the beauty of it all is, they put no plumes or flags upon their triumphs. Neither pausing nor gloating, they push on to new experiments, new realms of adventure, to dream and to do, giving to the world their harvest, these "fire-hearts who sow our furrows". It means a good deal, no doubt, that the electrical industry in all its branches employs something like one and one-half million workers, and some eighteen to twenty billion dollars of capital, and that three or four percent of our population live directly from its revenues. But more important still is the intimate, permeating relation of electrical energy to every other industry and every individual throughout the civilized globe. You can't get away from it unless you go into the wilds, catch your own food and make your own clothes and your own shelter, with tools fashioned by your own hands. And the chances are it would reach you there. So it is bound to be a great business, worthy of any man's ambition if he has the genius of a worker and the spirit of a producer. Big things have been done, but there are bigger to do. Let new discoveries come when they will. We cannot hurry them nor predict what they hold for us or for posterity. There is plenty to do that we know about. The industry has grown so rapidly, the art has improved so frequently under the stimulus of demand that the new standards of one year were superseded the next. Apparatus and methods become antiquated long before the amortizing capital can be found. As a consequence there are tremendous wastes going on which must sooner or later be stopped. The engineer points the way. The economist and the financier must give their aid. Above all things the public itself which is so reliably and so cheaply served by the utility companies, which indeed owns the utility companies, must see to it that these companies, under the proper regulation which they welcome, are permitted by adequate rates and by proper legislation to maintain their properties at high efficiency and with a fair rate of return. The public service company is a public benefit. You can't figure it any other way. That being so, it is to the interest of every community and to the national interest of the country that it have the most intelligent public co-operation and support.

E. H. Sniffin

The Problem of the Electric Railways

"Things have changed somewhat in their time", and so has the electric railway industry. In fact, things in this industry have developed a marked change for the better. The men in charge of electric railway properties today, by and large, are men of vision. There is hardly one who does not thoroughly grasp the problems confronting them.

It is, however, one thing to understand a problem and know what the solution is, but quite another to find ways and means to achieve the desired results. This latter is really the biggest task confronting electric railway executives. The one big obstacle standing in the way in most instances, is the public itself—meaning by this, all that public opinion and public good will embrace because, after all, this includes such things as credit, patronage, taxes, operating expenses, restrictions, etc.

Specifically, the great majority of electric railways need increased revenue in order to operate existing facilities satisfactorily. The public, on the other hand, need and should have more and better service. Our transportation facilities have not kept pace with the growth of communities and, as previously mentioned, the people themselves stand in the way, but the people generally do not know this, and hence cannot be expected to take steps to correct it. Great strides have been made during the past few years by progressive electric railway executives in making the public acquainted with facts regarding the difficulties encountered in providing adequate transportation facilities, but complete mastery of this modern art will take considerable time. Marked instances of its mushroom growth and achievements are quite apparent. Among these are the "Illinois Committee on Public Information", and similar organizations in other states; the constructive work and publicity of the American Electric Railway Association Reconstruction Committee and the Committee of One Hundred in connection with the Federal Electric Railway Commission; the Committee on Merchandising Transportation, Electric Railway Freight Haulage, and numerous other invaluable accomplishments of the American Electric Railway Association, the Central Electric Railway Association and other state associations. Complete mastery of the art of publicity will not be effected and the full measure of its force will not be secured until national and state-wide activity is backed up and fully supported by local publicity work and performance.

The electric railways need credit. It is quite impossible to get it with an inadequate income. It is almost impossible to get an adequate income without

the good will of the public; hence, the necessity of cultivating and establishing the good will of each local community.

Practically all railway executives are alive to the potent force of this abstract thing which we call "publicity". In the past many thought it consisted very largely in having one man write copy for use in the papers or in pamphlets. But they know now that it is a very much bigger thing—a sort of phantom giant force that is susceptible of direction and guidance and, when properly guided, it is capable of producing remarkable results. It becomes really active only when every executive and subordinate officer is thoroughly imbued with the spirit of the game, and then only when it is the job of some strong staff officer or headed up by a manager of public relations, with a staff of copy writers.

Recently a university professor presented an outline of a four-year university course planned as a special administrative or executive training course. The four years were divided up into groups of studies in the various branches of electric railway operation running for three or four months each. Thus there was civil engineering to cover track and bridges; a few months in electric engineering, power plants, cars and locomotives; some more on transmission lines; and other periods on accounting, banking, passenger and freight traffic, etc. I told him he had left out the most important study of all, and that was a fundamental grasp of how to deal with people—both employes and the public. And herein lies the former missing link in the public utility game. Most of us were trained on the engineering and physical side of the industry, and few gave much thought to the very important thing we now call "publicity" for want of a better or more descriptive term.

Therefore, as stated at the outset, things have changed somewhat; the smoke screen has been cleared away. It is now generally accepted that the one biggest nut to crack is that of securing the good will of the people we serve and their representatives. It is regretable that, when the industry as a whole had made such a good running start in this game, a business depression should set in; on the other hand, it may all be for the best. It will likely prove to be of great value in relieving the tension and thus permit more deliberate thought and action during the few months of business let-up. It should not, however, be an excuse for "marking time" but rather a time for thorough organization and preparation. The people generally will have relaxed and will be more inclined to stop, look and listen to advice and information. Without doubt, business will come back in a few months. It always has come back and the general needs of the country are such that actual requirements now existing will tend to restore business as soon as the people feel that prices have reached a new normal level, and a few months will, we believe, establish this. One sure way to help this is to get the public to favor public utility demands for increased revenue and then tell them about the new cars and other equipment that have been purchased to provide better service.

MYLES B. LAMBERT

Present Trend of Electrical Development

The present trend of electrical development, as it has been for several years, is toward an ever widening use of electricity in every sphere of human activity. This movement has been so rapid, and its results so conspicuous, as to awaken the industry to a realization that its proportions have changed. For many years the products of the industry which predominated were those used in power houses and on street cars. Then the motor had its day in the manufacturing field. And now the home and the farm are turning out to be the biggest market of all. Today for every dollar spent for electrical apparatus for the purpose of generating electrical current, three dollars are spent to transmit and distribute it to users, and eight dollars are spent for apparatus and supplies to utilize it. The ratio of consumption to generation is now eight to one, while not so long ago it was only three to one.

Until about fifteen years ago, the electrical railway was the thing but since then, due to causes with which we are all familiar, that branch of the industry has come upon evil days, and committees of one hundred, with a sublime and touching faith, make solemn and obsequious declaration of its wrongs.

In the meantime, the central station people, as we call them in the vernacular of our industry, have come to the front. They had a hard time in the early days when they had only light to sell. They wisely took on power and that helped a lot. They kept on plugging and digging and finally they struck a reservoir greater than any they had previously tapped. It turned out to be a "gusher" for they had finally reached the great American public in a new way, with comfort-giving and burden-lightening electrical service; and the use of electricity now goes beyond the bounds of industry and reaches the place of business and the home. It has at last become the universal servant of mankind.

The principal result of this change, which was not abrupt but gradual, was to make electrical apparatus known to the public, to rob it of its mystery and to have it accepted as merchandise, similar to other goods purchased over the counter. Out of the eight dollars spent for apparatus to consume and utilize current one-half, at least, is spent by the general public, and out of the three dollars spent for transmitting current (which includes the wiring of buildings) almost two dollars is also ultimately spent by the public. Therefore, out of every twelve dollars spent six dollars are spent by the public. Half, at least, of the electrical market is now removed from the field of technical negotiation and is conducted on mercantile lines. The public can be

reached only by merchandising methods. These involve problems of quantity manufacture, warehousing, distribution through middlemen and other problems of a commercial nature which have been met and solved by merchants down the ages, but which are new to us. While they differ from the highly technical ones involved in the design and production of electrical apparatus, they are, nevertheless, keenly interesting, and the electrical industry is endeavoring to meet them with an open mind, free from the retarding influences of inherited bad business practices, and upon a high plane of business ethics. The engineering mind should, after proper experience, be able to contribute something to the methods of commerce, and the electrical industry now has a special opportunity in that particular.

The most remarkable features of this extraordinary development have been the "electrification" of the household and of the farm. Electrical devices have lightened the burdens of the housewife and have helped the farmer to increase production.

While the commercial or merchandising development stands out most prominently in the present situation, there are other tendencies which should be noted. One phase of the widening use of electricity has been particularly noticeable in the field of manufacturing. Not only has motor drive been wonderfully extended, but the use of electricity otherwise in manufacturing processes, particularly in the form of heat producing devices, has been notable, and has been developed to a point where wonderful possibilities are in sight. It is held by some engineers that the consumption of electrical current in heat for industrial applications will in time exceed the consumption of current for motor power drive.

Electricity now has a recognized, acknowledged position. It is estimated that this country now needs at least a million homes, fifty thousand factory and railroad buildings and twenty thousand public buildings. Is it conceivable that any one of them will not be wired? The architect would as soon think of leaving off the roof.

There has been a tendency in the electrical industry towards co-operative effort which has been remarkable. It is doubtful whether anything of the kind has ever occurred in any other industry, and it is fitting that this comparatively new, young, vigorous industry should set an example for all others. And it is well that this spirit has inspired the industry, for the enormous and rapid development has brought into existence a large number of individual units in each branch of the industry. There are several hundred manufacturers of electrical apparatus, several thousand distributors of all kinds and several thousand public utilities. It is something to be proud of when we think that the progress so far made has been based on the intrinsic merit of the products of the industry and developed under methods of clean competition.

JOHN J. GIBSON

The Electrification of Industry

The industries of this country have been large purchasers of electrical machinery during the past six years. This buying has been continuous and in great volume, except for a short period of uncertainty following the signing of the Armistice. During the war period the industrial and mining companies were first called upon to purchase machinery for manufacturing war materials in great quantities and supplying the requirements of a hastily mobilized army. Somewhat later, additional machinery was required to supply the enormous demands of the people for all classes of merchandise, both necessities and luxuries.

As is well known, the products of the first phase of this period, from an economic point of view, have been dissipated. However, the money placed in circulation started an era of prosperity in all lines of manufacture which was accentuated to some extent by the mental reaction of the people from the thrift practiced during the war, by the greater private incomes and by the restrictions imposed upon manufacturers of non-essentials during war conditions.

The purchases of machinery by industrial organizations have been largely for plant expansion to obtain increased output. The dominating fact of interest to all branches of the electrical industry is that in this expansion practically all industrial organizations planned, as a matter of course, to use electrical machinery for their power requirements and furthermore, that such electric power was purchased from central power stations wherever possible, in preference to making the investment for a private source of supply.

While these factors have caused a severe strain upon the facilities of all branches of the electrical industry,—manufacturer, distributor and central station, yet the recognition of the advantages of electric power by all industrial organizations is a source of great satisfaction and hope for the future of the electrical business.

The coming year will undoubtedly see the purchase of improved modern machinery for rehabilitation purposes, looking towards more economical production to meet competitive conditions. It is confidently felt, however, that electrical apparatus and machinery will play just as important a part in this phase of the general business situation as it has in supplying the power for plant extensions.

The large field for the application of electrical machinery and apparatus to all industries, the development of new and improved apparatus by the engineers and the increasing popularity of electrical devices among all classes of people gives encouragement for the future to all branches of this great industry.

J. M. CURTIN

Enameling in the Automobile Industry

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Wonderful advances have been made during the last decade in the manner of applying paint and enamel to automobiles. The original method was to apply air-drying paint or enamel by hand with a brush. The next step was dipping the various small metal parts in a baking enamel and then baking them in gas-fired ovens. The hand painting of large parts, such as chassis and body has been replaced by the use of an air spray, using a baking enamel. The gas oven, on account of its many disadvantages, is being supplanted by electrically-heated ovens. These modern methods are well exemplified in the automobile plants of the Jordan Motor Car Company and the Cleveland Automobile Company in Cleveland, Ohio. The methods used in these plants and the results of tests made on their electrically-heated ovens are discussed in this article.

THE ENAMEL for many of the small parts at the plant of the Jordan Motor Car Company is baked in an electrically-heated oven of the semi-continuous conveyer type. This oven, Fig. 1, is 20 ft. long, 9.5 ft. wide, and 7.75 feet high inside measurement. It is thermally insulated with four inches of non-pareil brick and is encased with sheet iron linings. The conveyer extends through the oven and for about 30 feet outside of the oven at each end, returning over the top as shown in Figs. 1 and 2. It is motor driven and can be operated in either direction. The ventilating inlet air ducts are located in the floor along the sides of the oven, and have a series of holes over their entire length, so that the incoming air is evenly distributed along the sides directly underneath the heaters which are mounted on the side walls. The exhaust ducts take the air from near the floor at the four corners of the oven and deliver it to the outside of the building. The air is handled by a motor driven exhaust fan.

FIG. 1—SEMICONTINUOUS CONVEYOR TYPE OVEN FOR BAKING ENAMEL ON AUTOMOBILE PARTS

The electrical heating equipment consists of 64 oven heaters having a total capacity of 173 kw. The heaters are controlled by a three-phase, double section control panel. This panel is so arranged that one or both groups of the heaters can be operated by the oven thermostat. At present both sections are being controlled by the thermostat. Doors at each end are equipped with switches which cut off the power to the heaters when either door is opened. This eliminates any danger from live connections, and also the possibility of wasting heat by having the heaters turned on while the doors are open.

At each end of the conveyor is a dip tank, one of which contains the first coat enamel, and the other that for the second and third coats. These dip tanks are filled from an elevated storage tank, which is supplied by motor-driven pumps taking the enamel from the drip tanks which are located underneath the conveyor at both ends of the oven.

FIG. 2—OVEN AND DRIP TANK
The fenders on the conveyor are ready to be run into the oven.

The parts as received from the shop are often rusty and greasy, and must be cleaned thoroughly before they can be enameled, as the durability and finish of the enamel depends upon the smoothness and cleanness of the parts. To remove the rust, they are dipped in a muriatic acid bath, Fig. 3, and then rinsed thoroughly with water. They are next dipped in a caustic soda bath, Fig. 4 to remove the grease. After the parts have been thoroughly rinsed again and dried, they are rubbed with fine sand paper to remove all roughness.

From the cleaning room the parts are taken to the first coat dipping tank, where they are dipped and hung on the conveyor to drip. After dripping a sufficient length of time, they are run into the oven and another load is dipped and hung on the conveyor to drip. The

average baking period is about 50 minutes. This allows about 15 minutes for dipping the next load, and 35 minutes for it to drip before the first load is removed from the oven. When the first baking has cooled sufficiently, it is taken from the conveyor into the rubbing room Fig. 5, where it again receives a thorough rubbing.

The heat control of the oven is entirely automatic and no labor is required for its operation other than dipping the parts and hanging them on the conveyor.

TABLE I—OPERATING CHARACTERISTICS OF ELECTRIC OVEN

Bake	1	2	3	4	5	6	Avg.
Pounds Baked	555	293	1043	683	381	638	597
Minutes for Dipping	21	12	22	23	14	16	18
Minutes for Dripping	37	53	37	36	44	41	41
Minutes Baking	72	60	60	60	65	45	63
Kw-hr.	65.6	67.2	78.4	57.6	54.4	52.8	67.7
Lbs. Baked per Kw-hr.	9.8	4.4	13.3	11.8	7.0	12.1	9.0
Min. Current was on	22	22	28	21	20	19	22

Tests were made recently to determine the operating characteristics and the cost of operating the electric ovens. The results obtained for the different bakes are shown in Table I and the temperature curves in Figs. 6 and 7. All the tests were on the last or finish coat.

Although the average number of pounds baked per kilowatt-hour is somewhat lower than is common in ovens of this type, some of the bakes, taken under favorable conditions, show a very good efficiency. It seems that the two factors which affect the efficiency most are the number of pounds put into the oven per bake and the length of time that the power is cut off between the bakes.

FIG. 3—REMOVING RUST BY DIPPING PARTS IN A MURIATIC ACID BATH

Taking up the bakes in their order, No. 1 is about the average in weight, and the length of time elapsed, between cutting off the power from the proceeding bake and the start of this bake was slightly below the average. The efficiency was what could be expected from an oven of this type. In No. 2 bake, the load was very light and the length of time that the power was off, between the bakes, was considerably above the average. As a result the efficiency was very low. The third bake had rather a heavy load and the time interval between this and the previous bake was about normal, as a result the efficiency was high. A comparison of bakes No. 4 and No. 6 shows that while the load of No. 6 was less, the efficiency was higher. This can be accounted for by the fact that the time the power was off preceding the bake was 27 minutes against 35 for No. 4. No. 5 bake had both a light load and a 52 minutes time interval with power off before the bake was started.

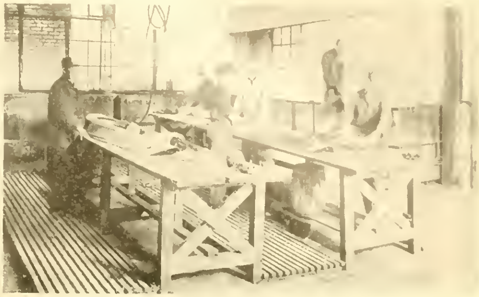

FIG. 4—CAUSTIC SODA BATH AND CLEANING TABLES

Grease and dirt are removed in the caustic soda bath. The roughness is removed by rubbing the parts with fine sand paper.

On the basis of nine bakes per day as shown on the temperature chart, Fig. 7, using the average energy consumption of 68 kw-hr. per bake and the number of cars per day as 22, the kw-hr. consumption per car would be 27.6. At a power rate of 1.63 cents per kw-hr. this would amount to 45 cents per car.

FIG. 5—RUBBING ROOM

After the first baking has cooled all the fenders receive a thorough rubbing.

The uniform temperature line on the temperature chart, Fig. 6, from 7 P. M. to 10 P. M. shows the temperature held during a test to determine the radiation of this oven with the doors and all the vents closed. This test shows a power loss of 56 kw-hr. due to radiation or an average loss of 56.6 watts per sq. ft. at a temperature of 400 degrees F. The results obtained in the radiation test are not the true losses of the oven under operating conditions. The temperature charts also show that the oven is up to the maximum temperature of 400 degrees for only a small percentage of the

time so that the average temperature of the oven for normal operation is much lower than the temperature applied during the radiation test. Temperature measurements, taken during the radiation test, show that for an average oven temperature of 400 degrees F., a temperature of 130 degrees F. was maintained on the outside walls, with a room temperature of 67 degrees F.

CLEVELAND AUTOMOBILE COMPANY

The oven used by the Cleveland Automobile Company for baking the enamel on their chassis is 120 ft. long, 100 inches high and 62.5 inches wide, outside dimensions. The entrance end is entirely open, the exit end has a flap covering the opening about one third the way down. The walls of the oven are constructed of two inch non-pareil brick encased between sheet iron linings. The work is carried on a conveyor through the oven at the rate of 2.5 ft. per min. This conveyor extends about 75 ft. at both ends of the oven. The oven is ventilated by a fan, which is driven by a 1.5 hp motor at 450 r.p.m. The size and the location of the intake and exhaust vents are shown in Fig. 8.

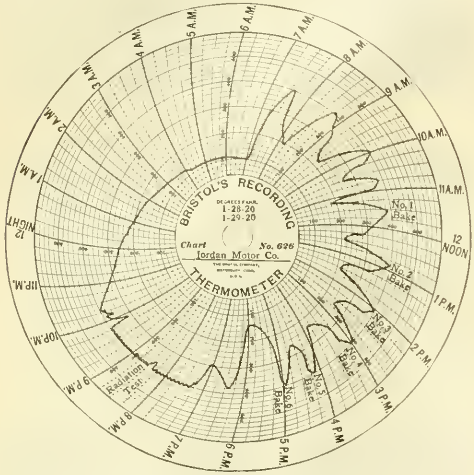

FIG. 6—TEMPERATURE TEST CHART
Showing operating characteristics of the electric oven.

The electrical heating equipment consists of 112 oven heaters, arranged along the sides of the oven and distributed to give a carefully graduated temperature throughout the oven. These heaters are connected in three circuits, two control and one constant heat circuit. Each circuit is controlled by a contactor panel, with a snap switch to control all three panels. The entrance and exit circuits are under thermostatic control. The electric heaters in the center are on the constant heat circuit. The entrance control circuit is on all the time while the exist circuit operates over a cycle of about 13.5 min. on and 46.2 min. off.

As the chassis is assembled, it is gradually worked toward the starting end of the oven conveyor. The completely assembled chassis is placed on the conveyor which carries it to the enamel spraying machines arranged so that the operators are on opposite sides of the chassis. These spray stations are provided with hoods equipped with motor-driven exhaust fans to carry off the fumes. The enamel used is especially made for use in spray machines. About 12 gallons of enamel are used on a daily output of 55 chassis or 0.2 gallon per chassis. Before entering the oven, the chassis are carefully inspected to see that no spot has been missed and that the coat is uniform. The trip through the oven requires about 50 minutes. As soon as they emerge from the oven, grease is placed in the transmission and housing, and most of the assembling is completed before the chassis leaves the conveyor.

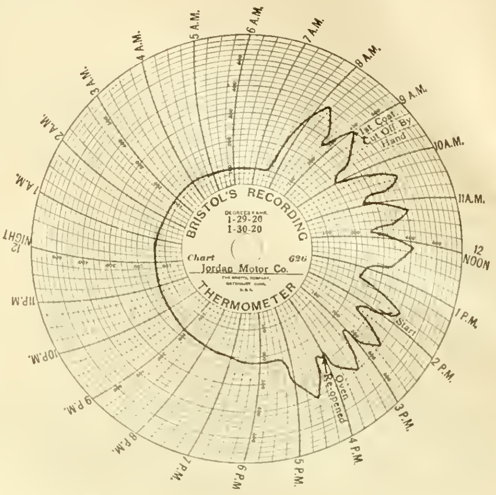

FIG. 7—TEMPERATURE CHART OF AN AVERAGE DAYS RUN

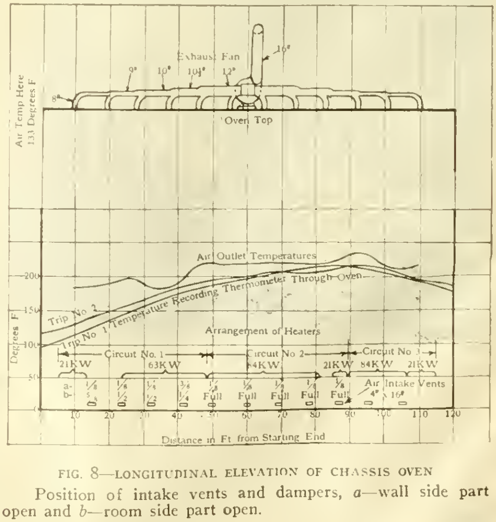

FIG. 8—LONGITUDINAL ELEVATION OF CHASSIS OVEN
Position of intake vents and dampers, *a*—wall side part open and *b*—room side part open.

Records of the temperature, throughout the oven, were made with a recording thermometer having the recording mechanism enclosed in a wooden box. The thermometer bulb was exposed to the heat and located in the center of the path of the work. The box was set on the conveyor and sent twice through the oven. The temperatures from the resulting chart were taken for points of time corresponding to ten feet of travel and plotted on the longitudinal elevation sketch of the oven, Fig. 8. The temperatures at each of the exhaust vents were taken by placing a thermocouple in the pipe about six inches above the oven top. These temperatures are plotted on the same sketch at points directly underneath the points at which they are taken.

At the time this data was obtained, the average hourly consumption was 213 kw-hr. and the number of chassis treated was six per hour. Each chassis weighed 750 pounds making a total weight of 4500 pounds per hour. This gives a production of 21.1 pounds per kw-hr.

The Electrical Characteristics of Transmission Conductors with Steel Cores

H. B. DWIGHT

STEEL CORES are frequently used in transmission line conductors, especially where the conductor material is aluminum, in order to increase the strength to a desirable amount. The steel core has a distinct effect on the electrical characteristics of the cable, and the amount of this effect may be estimated in the manner described in the following article.

THE effect of the addition of a steel core to a transmission line cable is, first, to decrease the resistance by an amount which may be two percent, more or less, and second, to decrease the reactance, usually by a smaller percentage. It will be shown later that a useful approximate rule for transmission calculations is to take the conductivity of the steel cored cable as being equal to the sum of the conductivities of the core (for alternating current) and the copper or aluminum, and to take the reactance of the complete cable as if the core were made of non-magnetic material, the same as the rest of the cable.

FIG. 1—SECTION OF CABLE AND CORE

Ordinarily the reactance of a transmission line is due chiefly to the magnetic flux in the air surrounding the conductors. The magnetic flux in the air is not of interest in the present problem however, for it cuts both the core and the outer wires of the cable equally. The effect of the flux inside the cable should be calculated, since it alters the distribution of current between the core and the remainder of the cable.

The non-magnetic wires of a cored cable form a tube of outer radius r and inner radius g, Fig. 1. Neglecting the current in the core, which is small, the total current inside the circle of radius x is,—

$$I_x = \pi i (x^2 - g^2) \text{ abamperes} \quad (1)$$

Where i is is the current density in abamperes per square centimeter, and where the dimensions are in centimeters. The flux density at radius x is,—

$$\frac{2 I_x}{x} = 2 \pi i \left(x - \frac{g^2}{x}\right) \text{ lines per sq. cm.} \quad (2)$$

The total flux in the ring outside the circle of radius x is obtained by integrating from x to r and is equal to,—

$$\phi_x = \pi i \left(r^2 - x^2 - 2g^2 \operatorname{logh} \frac{r}{x}\right) \text{ lines per cm.} \quad (3)$$

The reactive drop at radius x due to the above flux is,—

$$j \omega \phi_x = j \omega \pi i \left(r^2 - x^2 - 2g^2 \operatorname{logh} \frac{r}{x}\right) \text{ abvolts per cm.} \quad (4)$$

Where $\omega = 2 \pi f$ and where f is the frequency in cycles per second.

To find the average reactive drop due to the above flux multiply the element of area, $2 \pi x\, dx$, by the drop in that element, given by (4), integrate over the section of the tube and divide by the area of section of the tube. This gives,—

$$\tfrac{1}{2} j \omega \pi i \left(r^2 - 3g^2 + \frac{4g^4}{r^2 - g^2} \operatorname{logh} \frac{r}{g}\right) \text{ abvolts per cm.} \quad (5)^*$$

Assume that the diameter of the core is 1/3 that of the complete cable, which is usually very nearly the case, then $g = 1/3\, r$, and the average reactive drop in the tube is,—

$$\tfrac{1}{2} j \omega \pi i r^2 \times \frac{13.10}{18} \text{ abvolts per cm.} \quad (6)$$

Let the total current in the tube, equal to $\pi i (r^2 - g^2)$, be represented by $(a + j b)$ amperes, Then the reactive drop in the tube is,—

$$\tfrac{1}{2} j \omega \times \frac{13.10}{18} \times \frac{9}{8} \left(\frac{a + j b}{10}\right) \text{ abvolts per cm.} \quad (7)$$

This is equivalent at 60 cycles to,—

$$0.0248\, j\, (a + j b) \text{ volts per mile} \quad (8)$$

Let R be the resistance of the tube in ohms per

*"The Inductance of Tubular Conductors," by H. B. Dwight, *The Electrical Review*, Feb. 9, 1918, p. 224.

mile. Then the impedance drop, taking into account only the flux considered above, is,—

$(a + j\,b)\ (R + j\ 0.0248)$ *volts per mile* .... (9)

Now the alternating magnetic flux considered above cuts the core as well as the tube. The total flux is given by (3), putting $x = q$, and is,—

$\pi\, i\, r^2 \left(1 - \frac{1}{9} - \frac{2}{9} \times [illegible] .0\right)$ *lines per cm.* .... (10)

The reactive drop in the core due to this flux is,—

$j\,\omega\,\pi\, i\, r^2 \times \frac{5.80}{9}$ *abvolts per cm.* .... (11)

Which is equivalent to,—

$j\ (a + j\,b)\ 0.0440$ *ohms per mile* .... (12)

Let the current in the steel core be $c + j\,d$ amperes. The impedance of the core due to its effective resistance and the flux inside the steel, may be taken with reasonable accuracy from the curves published in the JOURNAL for January 1919.** Let the impedance given by the curves be $R_1 + j\,X_1$ for a certain assumed current in the core. Then the drop in the steel core is,—

$(c + j\,d)\ (R_1 + j\,X_1) + j\ (a + j\,b)\ 0.0440$ *volts per mile* .... (13)

The current in the complete cable

$= E$ *(total admittance)*

$$= E\left(\frac{1}{R - j\ 0.0192} + \frac{1}{R_1 + j\,X_1}\right)$$

In this way the effective resistance R' and reactance X' of the complete cable may be calculated, since the total admittance found above is equal to $\frac{1}{R' + j\,X'}$

It is found that the current in the core is usually so small that its effect in producing magnetic flux in the outer part of the cable may be neglected, as was done in the above calculation. The current in the outer part of the cable is to the current in the core in the ratio of their admittances, and that is very closely in the inverse ratio of their resistances.

A few examples are shown in Table I. The resistances and reactances are in ohms per mile. The line reactances are based on spacings which would be usual for transmission line work. It may be observed from the table that a 683 000 circ. mil cable composed of 600 000 circ. mils of aluminum and a steel core, has a larger diameter and therefore nearly one percent less reactance than a 600 000 circ. mil cable without a core.

TABLE 1—EXAMPLES OF TRANSMISSION CABLES WITH STEEL CORES

Outer Wires of Cables	Core	Current Assumed for Core	R_1	R	R'	% Decrease in Resistance due to Core	% Decrease Calculated from R_1 and R Only	X_1	X'	X	% Decrease in Reactance due to Core
600 000 Circ. Mil Aluminum	5/16" Cable, Ordinary Steel.	30 Amperes 60 Cycles	7.6	0.153	0.150	1.8	2.0	2.0	0.760	0.754	0.8
600 000 Circ. Mil Aluminum	5/16" Cable, Ordinary Steel.	15 Amperes 60 Cycles	6.4	0.153	0.149	2.2	2.3	1.3	0.760	0.754	0.8
600 000 Circ. Mil Aluminum	5/16" Cable, Ordinary Steel.	30 Amperes 25 Cycles	6.5	0.152	0.148	2.2	2.3	1.1	0.317	0.315	0.7
400 000 Circ. Mil Aluminum	9/32" Cable, Ordinary Steel.	20 Amperes 60 Cycles	8.6	0.228	0.223	2.3	2.5	2.0	0.760	0.751	1.2
250 000 Circ. Mil Aluminum	No 6 B. W. G. Wire, Ordinary Steel.	12.5 Amperes 60 Cycles	20.8	0.364	0.359	1.3	1.8	9.8	0.767	0.761	0.8
150 000 Circ. Mil Aluminum	No. 8 B. W. G. Wire, Ordinary Steel.	7.5 Amperes 60 Cycles	23.3	0.605	0.592	2.1	2.5	9.0	0.777	0.773	0.6

Resistance and Reactance are in Ohms per Mile. X is the Reactance of a 600 000 circ. mil or 400 000 circ. mill., etc. Aluminum cable having no core.

This may be equated to (9) since the core and the tube are in electrical contact and take up a distribution of current such as to give the same voltage drop in each. Therefore,

Therefore,

$(c + j\,d)\ (R_1 + j\,X_1) = (a + j\,b)\ (R + j\ 0.0248 - j\ 0.0440)$
$= (a + j\,b)\ (R - j\ 0.0192)$ *volts per mile at 60 cycles* .... (14)

The term 0.0192 becomes 0.0080 at 25 cycles. This is the same as the usual equation for two impedances in parallel: Thus, let each side of equation (14) be equal to E

$$\text{Then, } a + j\,b = \frac{E}{R - j\ 0.0192}$$

$$\text{and, } c + j\,d = \frac{E}{R_1 + j\,X_1}$$

A 683 000 circ. mil cable with an 83 000 circ. mil core has 0.2 percent more reactance than a 683 000 circ. mil all aluminum cable. Although the core offers a magnetic path to the flux of self-inductance, the amount of effective flux in the core is small, since a steel core of one-third the diameter of the cable carries only about one-fiftieth of the total current.

In conclusion, a close approximation to the electrical characteristics of a steel cored cable as used on transmission lines may be obtained by taking the resistance as equal to that of the core and the outer conductors connected in parallel, and by taking the reactance as equal to that of a non-magnetic cable of the same outside diameter. The direct-current resistance of the steel core should not be used, but only the value of the resistance to alternating current.

**"Resistance and Reactance of Commercial Steel Conductors," by H. B. Dwight, the JOURNAL for Jan. 1919, p. 25.

Efficiency of Adjustable Speed Motors

R. W. OWENS

THE CHOICE of a suitable adjustable speed motor for any application depends upon so many factors that a proper selection can be made only by comparison of all these factors. In power plants, for example, both alternating and direct-current supplies are often available and sometimes even both 115 and 230 volt direct-current power. In such cases, where adjustable speed motors having speed ranges of about 2 to 1, are required for driving small pumps, blowers, stokers or similar equipment, any one of the following schemes of speed control may be used:—

Direct-Current Motors—

1—Shunt field control
2—Armature resistance control
3—Amature voltage control

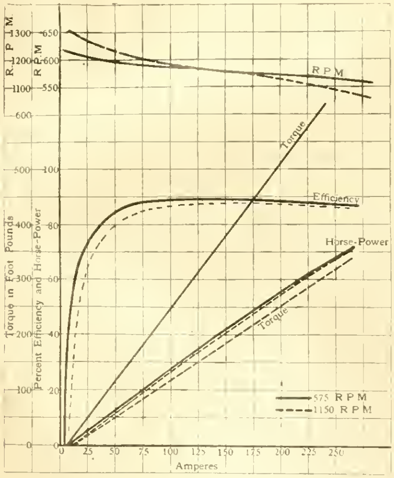

FIG. 1—TYPICAL CURVES FOR MOTORS WHEN SPEED IS CHANGED BY VARYING THE SHUNT FIELD

Alternating-Current Motors—

1—Secondary resistance control
2—Pole change.

There are other methods of obtaining adjustable speed, such as the single-phase commutator motor and the induction motor with different applied frequencies, which are suitable for certain applications. Only the schemes listed above, which are more common and more generally applicable, will be considered here.

For applications of this type, and with the possibility of choosing any one of these methods of obtaining an adjustable speed drive, the question of the relative efficiency of the different methods immediately arises. Data on efficiency at the normal speed is usually available or easily obtainable for the motors that would be used for any of these methods of speed adjustment. It is impossible to give data of the effect on efficiency of speed increase or reduction of speed, which would be applicable to motors of all makes. It is possible however to arrive at a few simple rules for estimating with fair accuracy the efficiency for any speed change on any motor. Though these rules are derived from the most fundamental relations, their derivation will be reviewed in order to point out the deviation from the fundamental rule in the case of actual machines.

DIRECT-CURRENT MOTORS WITH SHUNT FIELD CONTROL

The torque of a direct-current motor is directly proportional to the product of field strength and armature current. The speed of a direct-current motor is inversely proportional to the field strength. Therefore, if

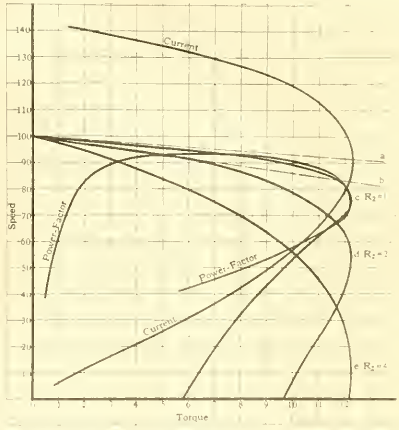

FIG. 2 SPEED-TORQUE CURVE OF AN INDUCTION MOTOR

Assuming the rotor resistance constant, and no primary resistance or magnetic leakage.

the speed of a motor is increased by weakening the field, the armature current must increase in direct proportion to the speed in order to maintain constant torque. Horse-power is directly proportional to the product of torque and speed, so that the horse-power output of such a motor, with torque remaining constant, increases directly with the speed. Assume a 40 hp, 575 to 1150 r.p.m. shunt wound motor driving a load which requires 40 hp at 1150 r.p.m., the load being of such a nature that the torque required to drive it is the same at all speeds. To reduce the speed of this motor to 575 r.p.m. requires that the field strength be doubled. With this doubled field strength only one half the armature current will be required to develop the same torque at 575 r.p.m. as was developed at 1150 r.p.m. From the

fact that the same torque is developed at one-half speed, it is apparent that the horse-power output at 575 r.p.m. is 20 hp. If the efficiency curves of this motor were the same at all speeds, the efficiency for any speed reduction with constant torque load could be obtained by reading efficiency at a load obtained by reducing the load at maximum speed in direct proportion to the reduction of speed.

For a direct-current motor with speed adjustment by shunt field control, the efficiency curves at different speeds are not quite identical, because part of the losses in the motor vary with the speed. The armature, commutating field, and series field I^2R losses obviously are independent of the speed, but friction and windage losses, iron loss and shunt field I^2R loss change with speed. The friction losses increase about directly with the speed, and windage losses increase roughly as the second power of the speed. The shunt field I^2R loss decreases as the speed increases. Its rate of decrease depends upon the degree of saturation of the iron which, in turn, changes as the speed increases, so that as higher speeds are reached this loss decreases directly as the speed increases.

TABLE I—EFFECT OF SPEED REDUCTION BY ARMATURE RESISTANCE

	Shunt Motor				Compound Motor				Series Motor			
Torque—lb. ft	183	183	46	46	183	183	46	46	183	183	46	46
R. p. m	1150	575	1160	575	1150	575	1300	575	1150	575	1770	575
Hp	40	20	10.2	5.04	40	20	11.4	5.04	40	20	15.5	5.04
Amperes	145	143.5	42.1	40.5	145	143.5	46.8	44.9	144.9	143.5	64.5	62.5
F. & W. losses—watts	640	270	640	270	640	270	770	270	640	270	1230	270
Iron loss—watts	1040	410	880	320	1040	410	1060	320	1040	410	1600	340
Shunt loss—watts	380	380	380	380	230	230	230	230	....	....	....	....
I^2R losses—watts	1450	17 020	170	4590	1600	17 170	230	5750	1810	17 400	430	10 000
Total losses—watts	3510	18 080	2070	5560	3510	18 080	2290	6570	3490	18 080	3260	10 610
Input—watts	33 350	33 000	9680	9320	33 350	33 000	10 790	10 330	33 330	33 000	14 820	14 370
Output—watts	29 840	14 920	7610	3760	29 840	14 920	8500	3760	29 840	14 920	11 560	3760
Efficiency—per cent	89.5	45.1	78.6	40.3	89.5	45.1	78.8	36.4	89.6	45.1	77.9	26.2
Estimated efficiency	....	44.8	....	39	....	44.8	....	35	....	44.8	....	25.3

The change of iron loss with change of speed is complicated by the effect of field distortion, so that, for one design of motor, it may decrease with increasing speed while for another design it may increase. The general tendency is the latter, but for moderate ranges of speed adjustment, that is ratio of speeds up to about 2 to 1, the increase of iron loss is quite small. With friction, windage and iron losses increasing and shunt field loss decreasing with increasing speed, it is apparent that the nature of the change in the sum of these losses depends upon their relative magnitudes. For the usual types of commercial motors with, say, 2 to 1 speed range, the sum of these losses increases slightly with increased speed, so that for any load the efficiency at the high speed is lower than the efficiency at the low speed. This change in efficiency is relatively small however. Fig. 1 shows calculated efficiency curves for a 40 hp, 575 to 1150 r.p.m. motor. These curves are typical for this class of motors and will serve as a guide for estimating efficiency when speed is changed by varying the shunt field strength, the efficiency curve at one speed being known.

DIRECT-CURRENT MOTOR WITH ARMATURE RESISTANCE CONTROL

If the field strength of a direct-current motor is kept constant and the voltage applied to the armature is varied, the speed of the motor will change very nearly in proportion to the change of applied voltage. The speed of a motor may then be adjusted by applying different voltages to the armature or, as is the more usual procedure, since only one voltage is generally available, by inserting resistance in series with the armature so that part of the line voltage is lost in IR drop in the resistance and the remainder is available at the armature terminals. Torque being proportional to field strength and armature current, if the field strength remains constant and speed is changed by armature control, the armature current will change directly as the torque changes. For a constant torque load, therefore, the armature current will remain constant for all speeds. For such a load, if speed is changed by inserting resistance in series with the armature, the total applied voltage is constant, the current is constant, therefore the total motor input is constant. Output, however, being the product of torque and speed, decreases directly with speed. The efficiency of a motor driving a constant torque load with this type of control, therefore, decreases in direct proportion to the decrease of speed. This rule also applies when torque changes with speed.

TABLE II—EFFECT OF SPEED REDUCTION BY CHANGE OF VOLTAGE

	Shunt Motor				Compound Motor				Series Motor			
Torque—lb. ft	183	183	46	46	183	183	46	46	183	183	46	46
R. p. m	1150	575	1160	575	1150	575	1300	575	1150	575	1770	575
Hp	40	20	10.2	5.04	40	20	11.4	5.04	40	20	15.5	5.04
Armature amperes	143.4	141.9	40.5	38.9	144	142.5	45.8	43.9	144.9	143.5	64.5	62.5
Armature Volts	230	120.1	230	116.2	230	120.5	230	103.8	230	121.1	230	76.5
F. & W. loases—watts	640	270	640	270	640	270	770	270	640	270	1230	270
Iron loss—watts	1040	410	880	320	1040	410	1060	320	1040	410	1600	340
Shunt loss—watts	380	380	380	380	230	230	230	230	....	....	....	....
I^2R losses—watts	1450	1430	170	160	1600	1580	230	210	1810	1770	430	410
Total losses—watts	3510	2490	2070	1130	3510	2490	2290	1030	3490	2450	3260	1020
Input—watts	33 350	17 410	9680	4890	33 350	17 410	10 790	4790	33 330	17 370	14 820	4780
Output—watts	29 840	14 920	7610	3760	29 840	14 920	8500	3760	29 840	14 920	11 560	3760
Efficiency—per cent	89.5	85.6	78.6	77	89.5	85.8	78.8	78.6	89.6	86	77.9	78.7

Suppose that the torque decreases as the speed decreases, then the input decreases with the decrease in torque while the output decreases with the decrease in torque and also with decrease in speed. The ratio of output to input, or efficiency, then still decreases directly as the speed, or the efficiency, when developing any torque at reduced speed, is equal to the efficiency

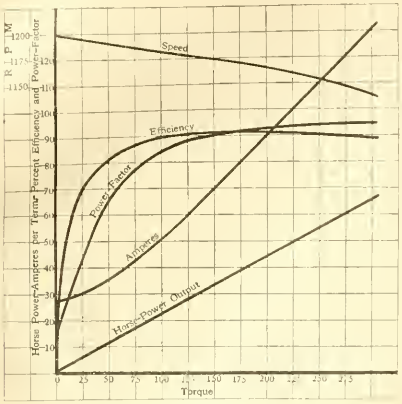

FIG. 3—PERFORMANCE CURVES FOR A 40 HP, SIX-POLE INDUCTION MOTOR

when developing the same torque at full armature voltage times the ratio of reduced speed to the speed at full armature voltage.

In the foregoing discussion the effect of friction, windage and iron losses has been neglected. However, if these losses vary directly as the speed, the rule given will still be exact. In a motor whose speed is adjusted by armature resistance, these losses do vary almost directly as the speed. Table I gives calculated losses for 40 hp, 1150 r.p.m. shunt, series and compound wound motors with speed reduced to 575 r.p.m. for a constant torque load and also for a load where torque changes as the second power of the speed. For this table a motor has been assumed with relatively large friction, windage and iron losses, yet it will be observed that the rule holds closely, especially where the speed reduction is approximately 50 percent.

DIRECT-CURRENT MOTOR WITH ARMATURE VOLTAGE CONTROL

Where means are available for changing the applied voltage without inserting resistance in series with the armature, the speed decreases nearly in proportion to the decrease in applied voltage. The input to the motor then decreases practically with the decrease in speed. Since the output decreases with speed the efficiency with this type of control for a given torque at any speed reduction is the same as the efficiency for that torque at full speed or the efficiency for moderate speed ranges is practically independent of the speed.

The conclusion reached in the above paragraph was based on the assumption that the speed of a motor decreases directly with the decrease of voltage applied to the armature. Actually the speed decreases directly with the decrease of counter-electromotive-force. Analysis of the difference between the assumed conditions and the actual conditions shows that it was assumed that the variable I^2R losses decrease with speed while they actually remain constant for a given torque. Also the effect of iron losses, friction and windage and shunt field losses was neglected. Table II shows calculated efficiencies for the same motors as in Table I except that the speed is adjusted by changing the voltage applied to the armature. Table II shows that, for a given torque, the efficiency decreases somewhat as the speed is decreased by armature voltage control.

INDUCTION MOTOR WITH SECONDARY RESISTANCE CONTROL

In an induction motor, just as in a direct-current motor, the torque developed is proportional to the product of field strength and armature current; or to use the terms ordinarily applied to an induction motor, torque is proportional to the product of primary flux and secondary current. When running at synchronous speed the rotor conductors rotate with the stator field and do not cut the stator flux. At synchronous speed, therefore, no voltage is induced in the rotor, no current flows in the rotor, and consequently no torque is developed. To develop torque, therefore, it is necessary for the rotor to run at a speed less than the speed of the rotating stator field. The flux cut by the rotor conductors and the rotor voltage induced is then proportional to the difference in speed between rotor and stator field, or to the slip. If the rotor resistance were constant, assuming no primary resistance or magnetic

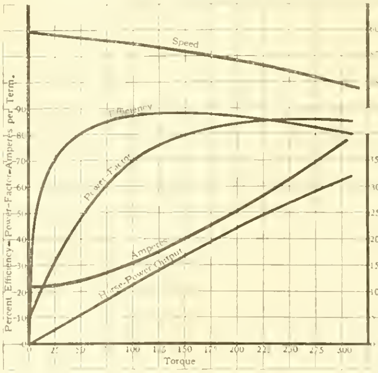

FIG. 4—PERFORMANCE CURVES FOR THE 40 HP INDUCTION MOTOR WITH TWELVE-POLE STATOR CONNECTIONS

leakage, the rotor current and consequently the torque would be proportional to the slip, or the speed-torque curve of an induction motor would have the form shown at *a* in Fig. 2. If the secondary resistance of this motor was doubled, to develop a given torque would re-

quire twice the secondary voltage or twice the slip required under the conditions for curve *a*. The speed-torque curve for this resistance would be that shown at *b*.

In an actual induction motor, primary resistance and magnetic leakage alter the shape of the speed-torque curves. Instead of the curves *a* and *b*, an actual motor will have curves of the form shown at *c* and *d*. However, in the actual motor the slip at any torque is still directly proportional to the secondary resistance as shown by curves *c*, *d*, and *e*. The same current and power-factor curves apply for all three speed-torque curves. For a given torque, then, the speed of an induction motor may be reduced by increasing the rotor resistance without affecting the power-factor or primary current. For an induction motor with speed control by rotor resistance driving a constant torque load, the input at reduced speed is equal to the input at full speed, and the output has decreased with the speed. The efficiency at the low speed then is equal to efficiency at full speed multiplied by the ratio of the low speed to full speed. This case is the same as a direct-current motor with speed controlled by armature resistance. Just as with the direct-current motor, if the torque changes with the speed, the efficiency at the reduced speed is equal to the efficiency when developing the low-speed torque at full speed, multiplied by the ratio of low speed to full speed.

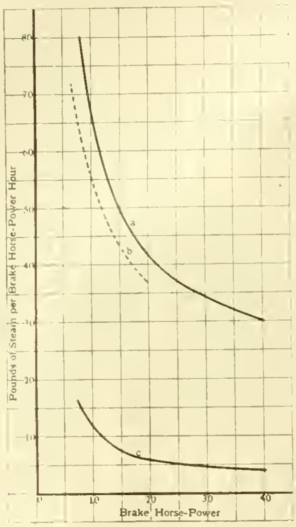

FIG. 5—STEAM CONSUMPTION OF NON-CONDENSING TURBINE

INDUCTION MOTOR WITH POLE CHANGE CONTROL

In an induction motor, speed may be changed by changing the number of primary poles. In general, only two combinations of poles are practicable. This arrangement, therefore, gives only two fixed speeds with no adjustment between these fixed speeds. For example, a 60 cycle motor may be wound so that its primary coils can be connected to give six poles with a corresponding speed of approximately 1160 r.p.m., also the primary connections can be changed to give twelve poles with a speed of about 570 r.p.m. This arrangement gives, in reality, two motor designs for the same full-load torque, the high-speed motor having twice the full-load horse-power that the low-speed motor has. For the same torque, it is to be expected that the efficiency and power-factor would be somewhat reduced with the low-speed connection. However, when two pole combinations are obtained with the same primary winding, both of these combinations cannot be equally effective. The primary winding is so designed as to be reasonably satisfactory for the small pole combination and, therefore, it is a winding of relatively high resistance and reactance in proportion to its effectiveness when used for the large pole combination. The efficiency and power-factor at the low speed therefore, are considerably lower than at the high speed for the same torque at both speeds. Fig. 3 shows performance curves for a 40 hp, six-pole motor, and Fig. 4 shows curves for the same motor with twelve-pole stator connections.

SMALL STEAM TURBINES

When steam is available for power, a choice of the most efficient type of drive cannot be made without considering the small steam turbine. In Fig. 5 curves *a* and *b* give the steam consumption of a non-condensing turbine of about 40 hp. Curve *a* represents steam consumption with two nozzles, and curve *b* is the steam consumption with one nozzle. These curves are approximately correct for small ranges of speed adjustment. Where a turbine of this type can be used, the total steam consumption of the main plant probably is about 18 pounds per kilowatt-hour. Allowing an efficiency of 84 percent for intermediate equipment, as transformer and motor-generator set, a steam rate of 21.5 pounds per kilowatt-hour or 16 pounds per hp-hour is obtained for power delivered to the terminals of a direct-current motor. A motor with 90 percent efficiency, taking power from the main plant then will use 17.8 pounds of steam per hp-hr. delivered. Comparing this figure with curves *a* and *b* Fig. 5, it appears that an efficient motor drive is much more economical than a small turbine drive.

This is not the case, however, when the exhaust steam from the turbine can be used for feed water or general heating. Curve *C* Fig. 5 gives approximately the steam consumption of the small turbine when the turbine is credited with the total heat of the exhaust steam. Comparing this curve with the figure of 17.8 pounds per hp-hour for the motor drive, it is apparent that the small steam turbine drive may be much more economical than a motor drive where a large part of the exhause steam can be used.

Phase Transformation With Autotransformers

Three-Phase to Two-Phase Three-Wire

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IN TRANSFORMING from three-phase to two-phase with Scott-connected autotransformers, it is often desirable to obtain a two-phase three-wire system instead of a two-phase four-wire system. The two-phase four-wire system has been thoroughly discussed by Mr. E. G. Reed.* A different connection is necessary for the two-phase three-wire system. There are three cases to be considered.

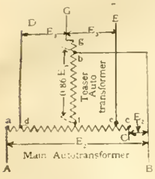


FIG. 1—WHERE THE TWO-PHASE VOLTAGE IS LESS THAN 122.5 PERCENT OF THE THREE-PHASE VOLTAGE

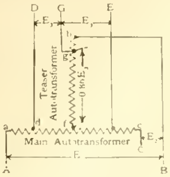


FIG. 2—WHERE THE TWO-PHASE VOLTAGE IS GREATER THAN 122.5 PERCENT OF THE THREE-PHASE VOLTAGE

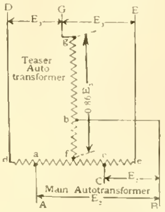


FIG. 3—WHERE THE TWO-PHASE VOLTAGE IS LESS THAN 70.0 PERCENT OF THE THREE-PHASE VOLTAGE

I—WHEN THE TWO-PHASE VOLTAGE IS LESS THAN 122.5 PERCENT OF THE THREE-PHASE VOLTAGE

Fig. 1 shows the autotransformers connected for this transformation. A condition of balanced load is assumed in order to simplify the problem. In determining the kv-a rating of the autotransformers it is necessary to know the currents in the various parts of the winding. The currents whose values are not obvious, are I_{fd} and I_{fb}. From Fig. 1,—

$$I_{fd} = I_{dD} + I_{aA}$$

The phase relations of these currents are shown in Fig. 4, and the numerical value is,

$$I_{fd} = (0.707\, I_2 - 0.866\, I_3) + j\,(0.707\, I_2 - 0.5\, I_3) \ldots. \quad (1)$$

The next step is to secure an expression for I_3 in terms of I_2:—

$$I_2 = \frac{Kv\text{-}a\ transformed}{2\, E_2}$$

$$I_3 = \frac{Kv\text{-}a\ transformed}{1.732\, E_3}$$

Combining these equations gives,—

$$I_3 = \frac{2\, E_2}{1.732\, E_3}\, I_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Substituting this value in equation (1) gives,—

$$I_{fd} = I_2 \left[\left(0.707 - \frac{E_2}{E_3}\right) + j\left(0.707 - 0.577\,\frac{E_2}{E_3}\right)\right]$$

$$= I_2 \sqrt{\left(0.707 - \frac{E_2}{E_3}\right)^2 + \left(0.707 - 0.577\,\frac{E_2}{E_3}\right)^2}$$

$$I_{fd} = I_2 \sqrt{1 + 1.333\,\frac{E_2^2}{E_3^2} - 2.23\,\frac{E_2}{E_3}} \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The current in the remaining part of the main autotransformer is I_2. The sum of the products of the voltage and the current in the two parts of the main autotransformer winding gives its kv-a rating as follows:—

$$Kv\text{-}a\ of\ main\ autotransformer = E_3\, I_{fd} + (1.414\, E_2 - E_3)\, I_2$$

$$= I_2 \left\{ E_3 \sqrt{1 + 1.333\,\frac{E_2^2}{E_3^2} - 2.23\,\frac{E_2}{E_3}} + 1.414\, E_2 - E_3 \right\} \quad (4)$$

$$The\ total\ kv\text{-}a\ transformed = 2 E_2\, I_2\,. \quad (5)$$

Then,—

$$\frac{Kv\text{-}a\ of\ main\ autotransformer}{Kv\text{-}a\ transformed} =$$

$$\frac{E_3}{2}\sqrt{\frac{1.333}{E_3^2} - \frac{2.23}{E_2 E_3} + \frac{1}{E_2^2}} + 0.707 - 0.5\,\frac{E_3}{E_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

From Fig. 2,—

$$I_{fb} = 1.414\, I_2 - I_3$$

$$= I_2\left(1.414 - 1.154\,\frac{E_2}{E_3}\right) \ldots \quad (7)$$

Therefore,—

$$Kv\text{-}a\ of\ teaser = 0.707\, I_{fb}\, E_2 + I_3\,(0.866\, E_3 - 0.707\, E_2)$$

$$= I_2\left(2E_2 - 1.632\,\frac{E_2^2}{E_3}\right)$$

and

$$\frac{Kv\text{-}a\ of\ teaser}{Kv\text{-}a\ transformed} = \left(1 - 0.816\,\frac{E_2}{E_3}\right) \ldots\ldots\ldots\ldots \quad (8)$$

Equations (6) and (8) give the total kv-a rating of the autotransformers, and to put them on the same basis as for a two-winding transformer, the expressions must be divided by two. The equations then become,—

$$\frac{Kv\text{-}a\ of\ parts\ required\ for\ main\ unit}{Kv\text{-}a\ transformed} =$$

$$\frac{1}{2}\left[\frac{E_3}{2}\sqrt{\frac{1.333}{E_3^2} - \frac{2.23}{E_2 E_3} + \frac{1}{E_2^2}} + 0.707 - 0.5\,\frac{E_3}{E_2}\right] \ldots. \quad (9)$$

$$\frac{Kv\text{-}a\ of\ parts\ required\ for\ teaser}{Kv\text{-}a\ transformed} = \frac{1}{2}\left(1 - 0.816\,\frac{E_2}{E_3}\right) \ldots \quad (10)$$

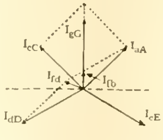


FIG. 4—PHASE RELATIONS FOR THE CONNECTIONS SHOWN IN FIG. 1

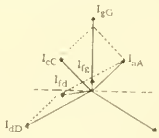


FIG. 5—PHASE RELATIONS FOR THE CONNECTIONS SHOWN IN FIG. 2

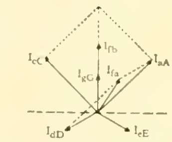


FIG. 6—PHASE RELATIONS FOR THE CONNECTIONS SHOWN IN FIG. 3

Example:—What is the ratio of the kv-a. rating of the transformer parts required to the kv-a. transformed, for a ratio of transformation of 440 volts three-phase to 440 volts two-phase three-wire?

For this case $\frac{E_2}{E_3} = 1$ and from equation (9),—

*In the JOURNAL for May, 1919, p. 216.

$$\frac{\textit{Kv-a of parts required for main unit}}{\textit{Kv-a transformed}} =$$

$$\frac{1}{2}\left[\frac{1}{2}\sqrt{1.333 - 2.23 + 1} + 0.707 - 0.5\right] = 0.184$$

Also, from equation (10),—

$$\frac{\textit{Kv-a of parts required for teaser}}{\textit{Kv-a transformed}} = \frac{1}{2}\left(1 - 0.816\right) = 0.092$$

II—WHEN THE TWO-PHASE VOLTAGE IS GREATER THAN 122.5 PERCENT OF THE THREE-PHASE VOLTAGE

Fig. 2 shows two autotransformers connected for this condition. An inspection of this figure and Fig. 5 will make apparent that the conditions relating to the

TABLE I—COMPARISON OF PERCENTAGES OF KV-A PARTS REQUIRED

For the Two-phase, Three-wire and Two-phase, Four-wire Systems

$\frac{E_3}{E_2}$	Percentages for Main		Percentages for Teaser		Total Percentages	
	Two-phase, Three-wire	Two-phase, Four-wire	Two-phase, Three-wire	Two-phase, Four-wire	Two-phase, Three-wire	Two-phase, Four-wire
0.2	48.30	43.30	41.85	38.46	90.15	81.76
0.4	32.65	33.40	33.70	26.90	66.35	60.30
0.8	12.10	18.34	17.40	3.80	29.57	22.14
1.0	18.40	14.42	9.20	6.70	27.60	21.12
3.0	48.00	38.70	29.60	35.55	77.60	74.25
5.0	54.40	44.60	37.75	41.35	92.15	85.95

main autotransformer are the same in this case as in Case I, but are different for the teaser.

$$I_{tg} = I_2 - 1.414\ I_2$$

Kv-a of teaser autotransformer =

$$0.866\ I_{tg}\ E_3 + 1.414\ I_2\ (0.707\ E_2 - 0.866\ E_3)$$

Substituting the value of I_2 from equation (2),—

$$\textit{Kv-a of teaser auto} = I_2\ (2E_2 - 2.45\ E_3)\ \ldots\ldots\ldots\ (11)$$

By the use of equation (5),—

$$\frac{\textit{Kv-a of teaser}}{\textit{Kv-a transformed}} = 1 - 1.225\ \frac{E_3}{E_2}\ \ldots\ldots\ldots\ldots\ldots\ (12)$$

Putting this relation on the same basis as for a two winding transformer it becomes,—

$$\frac{\textit{Kv-a of parts required for teaser}}{\textit{Kv-a transformed}} = \frac{1}{2}\left(1 - 1.225\ \frac{E_3}{E_2}\right) (13)$$

Example:—What is the ratio of the kv-a. rating of the transformer parts required to the kv-a. transformed, for a ratio of transformation of 220 volts three-phase to 440 volts two-phase?

For this case $\frac{E_2}{E_3} = 2$ and from equation (9),—

$$\frac{\textit{Kv-a of parts required for main unit}}{\textit{Kv-a transformed}} =$$

$$\frac{1}{4}\sqrt{1.333 - 1.115 + 0.25} + 0.3535 - 0.125 = 0.40$$

And from equation (13)

$$\frac{\textit{Kv-a of parts required for teaser}}{\textit{Kv-a transformed}} = \frac{1}{2}\left(1 - 1.225 \times 0.5\right) = 0.194$$

III—WHEN THE TWO-PHASE VOLTAGE IS LESS THAN 70.7 PERCENT OF THE THREE-PHASE VOLTAGE

From Fig. 3, which shows the connections for this condition, and Fig. 6 which shows the phase relations of the currents, it is apparent that I_{ta} has the same value as in Case I. Therefore,

Kv-a of main autotransformer =

$$1.414\ E_2\ I_{ta} + (E_3 - 1.414\ E_2)\ I_2$$

Or, referring to equation (2), and using I_{ta} in place of I_{td} in equation (3),—

Kv-a of main autotransformer = $2\ E_2\ I_2 \times$

$$\left[0.707\ E_2 \sqrt{\frac{1}{E_2^2} + \frac{1.333}{E_3^2} - \frac{2.23}{E_2\ E_3}} + 0.577 - 0.816\ \frac{E_2}{E_3}\right]$$

Using equation (5), and changing the equation to the same basis as a two-winding transformer,—

$$\frac{\textit{Kv-a of parts required for main unit}}{\textit{Kv-a transformed}} =$$

$$\frac{1}{2}\left[0.707\sqrt{1 + \frac{1.333\ E_2^2}{E_3^2} - \frac{2.23\ E_2}{E_3}} + 0.577 - 0.816\ \frac{E_2}{E_3}\right] (14)$$

In this case, the conditions relating to the teaser transformer are the same as in Case I.

Example:—What is the ratio of the kv-a. rating of the transformer parts required to the kv-a. transformed, for a ratio of transformation of 440 volts three-phase to 220 volts two-phase?

For this case $\frac{E_2}{E_3} = 0.5$ and from equation (14),—

$$\frac{\textit{Kv-a of parts required for main unit}}{\textit{Kv-a transformed}} =$$

$$\frac{1}{2}\left[0.707\sqrt{1 + \frac{1.333}{4} - \frac{2.23}{2}} + 0.577 - 0.408\right] = 0.25$$

And from equation (10),—

$$\frac{\textit{Kv-a of parts required for teaser}}{\textit{Kv-a transformed}} = \frac{1}{2}\left(1 - 0.414\right) = 0.293$$

Fig. 7 shows the variation of the kv-a. of transformer parts required to the kv-a. transformed, for both

FIG. 7—EFFECT OF VOLTAGE RATIO ON TRANSFORMER CAPACITY REQUIRED

The ordinates represent the ratio of kv-a of parts required to kv-a transformed.

the main and teaser autotransformers, for ratios of transformation $\frac{E_2}{E_3}$ ranging from 0.1 to 6. Table I gives a comparison of the percentages of the kv-a. of transformer parts required to the kv-a. transformed, for the two-phase three-wire and the two-phase four-wire systems.

Application of Steam Condensers—II

Selection of Size

F. A. BURG

THE SUBJECT of condenser selection from the standpoint of economics, has received less consideration than it deserves. An improper choice of the size of the condensers in a plant may cost thousands of dollars each year. Time spent in the selection of condensers is time well spent as thereby such losses can be prevented. To assist in a clearer understanding of the problem, the general procedure to follow, together with specific examples, are discussed in the following article.

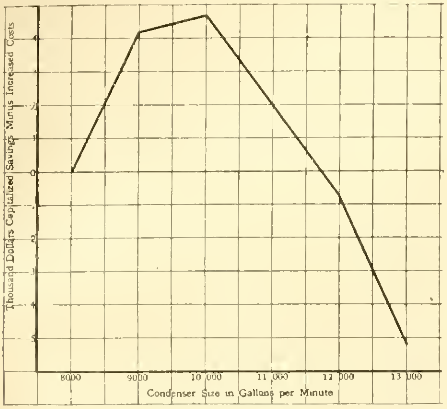


FIG. 1—DETERMINING MOST ECONOMICAL SIZE OF JET CONDENSER

The problem is by no means simple, when all the factors bearing on the selection are taken into consideration. At first glance it would appear that the size of the condenser can be determined if the vacuum to which the prime mover can effectively expand, the amount of steam to be condensed and the temperature of the cooling water are known; but there are a number of other factors that must be taken into account. "Rules of Thumb", such as proportioning the surface to the kilowatt rating of the main turbine, may be used to obtain an approximate size, or as a basis from which to start calculations, yet no such rule has been devised that will apply, except in a general way.

TABLE I—CALCULATIONS AND ESTIMATES FOR JET CONDENSERS

1 Cond. size gallons per minute	8000	9000	10 000	11 000	12 000	13 000
2 Total lbs. of steam	100 000	100 000	100 000	100 000	100 000	100 000
3 Vac. 75° water	27.86	28.0	28.11	28.19	28.26	28.32
4 Improvement in vacuum	0	0.14	0.25	0.33	0.40	0.46
5 Per cent corr. at 5% per in.	0	0.70	1.25	1.65	2.00	2.30
6 Sav. lbs. of steam per hr.	0	700	1250	1650	2000	2300
7 Sav. lbs. of steam per yr.	0	4 900 000	8 750 000	11 550 000	14 000 000	16 100 000
8 Cost of steam	0	$1715	$3060	$4030	$4900	$5620
9 Cost cap. at 15 per cent	0	11 430	20 400	26 900	32 700	37 400
10 Hp. for drive	240	260	285	315	340	370
11 Equiv. steam	2930	3170	3480	3850	4150	4520
12 Excess steam	0	240	550	920	1220	1590
13 Excess steam per yr.	0	1 680 000	3 850 000	6 340 000	8 540 000	11 130 000
14 Cost of steam	0	$588	$1348	$2220	$2990	$3870
15 Cost capitalized at 15 per cent	0	3920	9000	14 800	19 900	25 800
16 Maint. per yr.	$450	510	560	620	675	730
17 Excess maint.	0	60	110	170	225	280
18 Excess maint. cap	0	400	735	1135	1500	1870
19 First cost	23 000	26 000	29 000	32 000	35 000	38 000
20 Excess cost	0	3000	6000	9000	12 000	15 000
21 Line 9—15—18—20	0	$4110	$4665	$1965	$700	$5270

The condenser should not be chosen for one speci- · temperature of cooling water, or for one load on the ... turbine, but for the average temperature and the ... e load that will prevail throughout the year. ... e of the condenser should be taken into account only in its bearing on the cost of producing power, for the condenser that is cheapest in first cost is frequently the most expensive to operate.

Considerable data on various sizes of condensers is necessary before the various calculations can be made. First, estimate the average load on the turbine to be served by the condenser. This is most conveniently taken on a yearly basis, estimating the total number of hours per year that the unit will be in service, making sufficient allowance for shut-downs, and then the average load that will be carried while the unit is on the line. From the water rates of the turbine the average steam consumption for the estimated load can be calculated. The amount of steam for which the condenser should be designed is thus obtained.

For the cooling water temperature, the average temperature throughout the year should be taken. Actual statistics are preferable in arriving at the average, but where a log of the temperatures is not available as accurate an estimate as possible should be made.

The power required to drive the condenser auxiliaries is an important item, therefore an accurate determination of the pumping heads is essential. The head on the circulating pump of a jet condenser consists of the internal head, due to the vacuum, and the external head, due to the elevation at which the water is discharged and the pipe friction. This is also true of the pumping head on the condensate pump of a surface condenser. The head on the circulating pump of a surface condenser consists of the suction lift plus the discharge head (actual number of feet above the circulator to which the water is carried) plus the friction, including pipe friction and friction inside the condenser. In cases where the discharge pipe is sealed, and below the highest point in the circulating system, some allowance can be made on the total pumping head

for the syphonic effect. The power required to operate a hydraulic air pump is practically constant within the head limits for which it is designed. The power required for reciprocating air pumps can be varied somewhat by varying the speed but at a sacrifice in capacity. Steam jet air ejectors require a fixed amount of steam for each stage or group of nozzles, but the amount of steam required to operate them as a whole can be varied by cutting out some of the ejectors, if there are several in the unit. This is done at a sacrifice in vacuum.

In studying the auxiliaries of the plant to determine what type of drive to use, the heat balance must be taken into consideration. The drives for the various power plant auxiliaries should be selected on the basis of using all the exhaust steam for heating the boiler feed. It is practically impossible to design a plant to have the maximum boiler feed temperature at all times. The usual scheme is to have high feed water temperatures at light loads and somewhat lower temperatures at the heavier loads, in order not to waste exhaust steam at light loads. When the necessary amount of exhaust steam has been provided, the remainder of the auxiliaries should be motor driven.

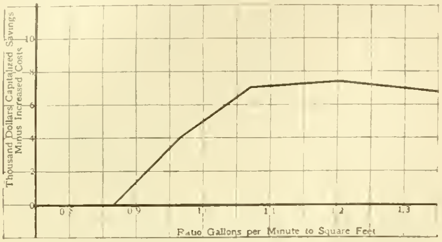


FIG. 2—DETERMINING MOST ECONOMICAL RATIO OF WATER CIRCULATED TO AREA OF A SURFACE CONDENSER

Cost data, together with maintenance costs and performance, must also be obtained on a number of condensers before the analysis is complete. The costs need be only relative as a comparison between the sizes is all that is necessary to determine the best one.

With all this data available, the general method of procedure is as follows: List all the condensers in tabulated form as regards size, beginning with one that is known to be too small for the application, and ending with one that is too large, using standard sizes in between. The proper condenser will be found somewhere among the condensers listed. With each condenser determine the vacuum that would be obtained when condensing the average quantity of steam with the cooling water of average temperature. Find for each size the improvement in vacuum in inches of mercury over the smallest one. The product of these last figures by the percentage correction per inch allowable on the turbine will give the percentage the steam passed will be reduced by the better vacuum. Applying these corrections in each case, determine the saving in pounds of steam per hour, and then per year, that each condenser will effect over the smallest size. Knowing the cost of producing steam, per thousand pounds, the saving in dollars per year is then determined. Capitalizing the savings at a fair percentage for fixed charges, will give the amounts that could justifiably be invested to effect such savings.

So much for the saving in steam on the main unit; next the condenser drive should be considered, for it is only by greater expenditure of power on the auxiliaries that such savings in steam as represented by the use of the larger condensers can be obtained. For each condenser find the amount of auxiliary power that will be required and the excess over the smallest size. Then find the cost, to deliver this excess power to the condenser. If the auxiliaries are steam driven, all the steam being used for heating the feed water, the only charge that can be made is for the heat lost in the steam in passing through the driving turbines. This is about 100 B.t.u. per pound, and the equivalent in live steam and cost of generating it can readily be found. If the auxiliaries are motor driven, the cost of power can be estimated from the cost of the steam required by the unit from which the motors receive their power, taking into consideration motor and generator efficiencies, and transmission losses. The costs of the excess power thus found and capitalized, at the same percentage as used for the cost of the steam saved, give in each case an amount which such an increased cost would represent in investment.

The maintenance can be treated in the same way as the cost of power, getting the excess over the smallest size and capitalizing it at the same percentage. Finally the cost of each condenser installed in the plant, adding any extra installation costs due to using a larger condenser, are set down and the excess found as before.

TABLE II—ESTIMATES TO DETERMINE SURFACE CONDENSER WITH MOST ECONOMICAL SURFACE TO WATER RATIO

1 Condenser size sq. ft.	15 000	14 000	13 000	12 000	11 000
2 Gallons per minute circulated	13 000	13 500	13 900	14 400	15 000
3 Hp. for drive	155	160	169	190	214
4 Hp. excess over 15 000	0	5	14	35	59
5 Equiv. steam at 12.2 lbs. per hp.	0	61	171	427	720
6 Equiv. steam per yr.	0	427 000	1 197 000	2 989 000	5 040 000
7 Cost of steam at 35c	$ 0	$150	$420	$1045	$1765
8 Cost of steam cap. at 15 per cent.	0	1000	2800	6970	11 770
9 Cost of condenser	64 000	61 000	58 200	55 400	52 600
10 Saving over 15 000 size	0	3000	5800	8600	11 400
11 Maintenance per yr.	5400	5100	4800	4550	4350
12 Saving over 15 000 size	0	300	600	850	1050
13 Saving in main cap. at 15 per cent.	0	2000	4000	5670	7000
14 Sav[illegible]	0	$4000	$7000	$7300	$6630

Having determined the foregoing, the only thing that remains to be done is to balance the savings against the increased costs to see which condenser is the most economical. Taking the capitalized savings and subtracting the capitalized excess operating and maintenance costs, also the excess installation costs, select the

condenser that shows the greatest difference, for it is this condenser that makes the greatest saving, all things considered. If the figures are plotted in the form of a curve using condenser sizes on the horizontal scale and capitalized savings minus increased costs on the vertical, the point where the curve reaches a maximum is the point of selection.

To illustrate the various steps mentioned, a concrete example is given. In this case for the purpose of

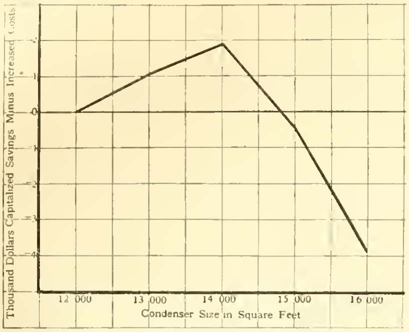


FIG. 3—DETERMINING MOST ECONOMICAL SIZE OF SURFACE CONDENSER

illustration all the data has been assumed and any of the figures given should be considered accordingly. Assume a 10 000 kilowatt plant with the following conditions: Operation 7000 hours per year average, at 80 percent load factor; steam is generated at 200 lbs. gage pressure, 100 degrees superheat; sufficient exhaust steam is available for heating without using turbine driven auxiliaries; the average cooling water temperature is 75 degrees; the external discharge head on the circulating pump is 10 ft., total head on the condensate pump is 80 ft.; cost of steam is 35 cents per thousand pounds. With this data in mind, a jet condenser and then a surface condenser will be selected.

For the jet condenser, the results of the calculations and estimates are shown in Table I. All results throughout are slide rule calculations. Plotting the results shown in line 21 of Table I, the curve in Fig. 1 is obtained. It will be noticed that the curve reaches its maximum point at the 10 000 gallons per minute condenser, and it is quite evident that this is the best condenser for the assumed conditions, since it is with this machine that the greatest saving is made. Analyzing the results it will be seen that the higher the load factor the larger the condenser that could be justified, since it is the saving in the steam on the main unit, by the use of higher vacuum, that plays an important part in the selection. For this reason an industrial plant with a low load factor should not choose as large a condenser for a given turbine as would the central station plant with high load factor.

Using the same set of conditions for the surface condenser selection, a slightly different problem arises, since another variable is introduced. The size of the condenser may be varied and the ratio of the gallons circulated to the surface in square feet may also be changed. It is, therefore, first necessary to establish the proper ratio of water to surface, and then proceed with the selection of the size of condenser with this ratio fixed.

To find the best ratio, first choose a vacuum, based on common practice, where it is expected that the condenser will operate most of the time, in this case say 28 inches with the 75 degrees feed water, when condensing 100 000 lbs. of steam per hour. Next find a number of condensers, with varying ratios of water to surface, that will give this vacuum. Then ascertain the cost of supplying power to the pumps, and the excess over the cheapest one to operate. Set down the first costs and the saving in cost over the most expensive one, which will also be the cheapest to operate. Determine the maintenance charges and the saving in maintenance over the largest size. Finally balance the capitalized savings against the capitalized costs, and the condenser showing the greatest difference has the best economical ratio. For the given case the calculations are tabulated in Table II, which shows that the 12 000 square foot condenser, circulating 14 400 gallons per minute, or the one having a ratio of 1.2 to 1, is the most economical. The results as indicated in the last line of Table II are represented in curve form in Fig. 2, and reach the maximum point at the 12 000 square foot size.

TABLE III—ESTIMATES TO DETERMINE SURFACE CONDENSER PRODUCING MOST ECONOMICAL VACUUM

1 Condenser Size sq. ft.	12 000	13 000	14 000	15 000	16 000
2 Gallona per minute circulated	14 400	15 600	16 800	18 000	19 200
3 Vacuum, 75° Water, 100 000 lbs. steam	27.98	28.1	28.21	28.28	28.34
4 Improvement in Vac. over 12 000 size	0	0.12	0.23	0.30	0.36
5 Per cent correction at 5 per cent per inch	0	0.6	1.15	1.5	1.8
6 Saving in steam per hour	0	600	1150	1500	1800
7 Saving in steam per year	0	4 200 000	8 050 000	10 500 000	12 600 000
8 Cost of steam at 35 cents	0	$1470	$2820	$3680	$4400
9 Cost of steam capitalized at 15 per cent.	0	9700	18 800	24 500	29 300
10 Hp. for drive	190	203	216	228	242
11 Excess over 12 000 size	0	13	26	38	52
12 Equiv. steam at 12.2 lbs. per hp.	0	159	317	463	634
13 Equiv. steam per year	0	1 113 000	2 219 000	3 241 000	4 438 000
14 Cost of steam at 35 cents	$ 0	$390	$776	$1153	$1580
15 Cost of steam capitalized at 15 per cent.	0	2600	5180	7700	10 520
16 Maintenance per year	3900	4230	4550	4850	5200
17 Excess Main. over 12 000 size	0	330	650	950	1300
18 Excess Main. capitalized at 15 per cent.	0	2200	4340	6330	8670
19 Cost of Condensers	54 200	58 000	61 600	65 000	68 200
20 Excess cost over 12 000 size	0	3800	7400	10 800	14 000
21 Savings vs. Costs 9—15—18—20	0	$1100	$1880	$430	$3890

Having selected the proper ratio, the next step is to select the condenser with this ratio that will produce the most economical vacuum. In arriving at this result it will be noted that there will be a slight chance for error, if the vacuum on which the ratio is chosen does not approximate that obtained later, but the difference

is so small that it can be disregarded for all practical purposes. The general method of procedure is the same, selecting various sizes and comparing them on a cost and savings basis. Thus Table III should be quite clear.

From Table III it is evident that the 14 000 square foot condenser, circulating 16 800 gallons per minute is the best condenser for this application. The results as indicated in the last line of Table III are represented in curve forms in Fig. 3. In the problem of the selection of the size it is quite apparent that the feed water treating question has not been considered. With a given type of condenser practically the same amount of treating will be necessary, and since it is only the differential that is pertinent, the feed problem may be disregarded.

The general plan followed in the foregoing is also applicable to the selection of almost any kind of apparatus, for it is only by comparing the different sizes and designs, and forecasting what each will do in service, that we are able to make the proper selection.

Power-Factor in Polyphase Circuits

A. NYMAN

The definition of "power factor in polyphase circuits" is receiving a good deal of discussion at the present time. The aim of this article is to present briefly some of the main considerations entering into this discussion.

THE term "power factor" as applied to single-phase circuits, owes its origin to an economic necessity. The capacity of the electric machinery and of the distribution network and the expense of supplying electric power are directly dependent on this factor. With the rise of polyphase systems, the same factor was applied to individual phases. As long as the loads were balanced, this factor was common to all phases and could be used to represent the load conditions accurately. As the number and magnitude of single-phase loads drawing power from polyphase circuit increased, it became more apparent that the old "power-factor" was insufficient. A new basis must be found for determining to what extent individual consumers should be held responsible for the loading conditions existing on the line.

A number of possible definitions have been in use. As long as most single-phase loads are approximately balanced one against the other, there is little difference in results given by various definitions. Lately, however, large power loads with considerable unbalance have come into use and made it desirable to standardize on a definition which would be satisfactory from technical and commercial viewpoint. The A. I. E. E. and the N. E. L. A. have formed a joint committee to carry out this standardization. This committee has brought forward a wide discussion of this subject.

In general, three classes of people are interested in a suitable definition of "power-factor":—

The producer of electric energy.
The consumer of electric energy.
The manufacturer of electric machinery.

In considering the conditions affecting central station operation, the presence of unbalanced load has a direct result in the rising losses in the generating units and distributing network. Comparing unbalanced load with a balanced load of the same kilowatts, the power station must bear the cost of additional coal burned and the interest and depreciation on the additional plant capacity. This additional cost could form a basis for defining power factor. The disturbance of voltage, as created by unbalanced load, is a far more serious feature; its result is poor service from the station. The unbalance in voltage, if large, cannot be easily corrected. Synchronous motors or phase balancers can minimize this effect, but must be located close to the source of disturbance in order to be effective. Lagging current in the line has approximately the same effect on regulation as unbalance. It can be corrected by suitable appliances, but in order to be most effective, the latter must be located close to the source of lagging current. The two causes of poor regulation may be corrected by separate means. The cost of correction can be estimated separately.

The above considerations suggest the use of two factors (1) To represent phase lag in the system, assuming all the load balanced—(2) To represent unbalance. Such a method of measurement could have an exact scientific basis and could be made to represent each load condition accurately. Several practical objections are raised against this method. The use of an additional term like "unbalance factor" would involve a further complication in determining the rate to be paid. Producers and consumers must all be conversant with the technical meaning of this new term in order to appreciate its importance and avoid disputes.

From the customer's standpoint both the quality of the service and the fairness and simplicity of the rates are factors of importance. The users of large single-phase loads must be assured that whatever penalty is placed on their type of load is commensurate with the actual cost of supplying this load and of maintenance of service to other customers. Certain consumers, such as large electric furnaces or single-phase railways, could be induced to install phase balancers. This would protect the rest of the system and bring the burden of unbalanced load directly to the customer.

Polyphase machinery on circuits with unbalanced voltages draws unbalanced currents. These currents,

while beneficial to the rest of the system, are a source of losses and reduction of capacity to the machinery through which they flow. Any scheme that would apply a single factor for both phase lag and unbalance would treat such load unfairly. With two sepearate factors, the unbalance existing in the polyphase machinery will not necessarily affect the charge. The unbalance factor can be simply overlooked. On the whole, a scheme for measuring phase lag and unbalance separately would be desirable, provided the calculations of rates were simple.

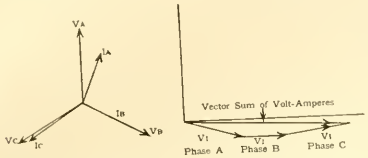


FIG. 1—DERIVATION OF POWER-FACTOR
For a particular case of unbalanced currents.

From the manufacturer's point of view, the discussions of unbalance factor brings up a number of points concerning the protection of polyphase machinery on unbalanced voltage systems. All such machinery is subject to additional losses when such voltage exists. These losses are partly distributed throughout the machine and partly concentrated in certain portions of the machines. Consider the case of an induction motor with the voltage in one phase higher than the others. This phase will draw a comparatively high current and the winding of this phase will be overheated. At the same time, an induced voltage is added to the rotor, which creates further losses distributed throughout the rotor.

For close technical analysis of working conditions, separate measurements of power-factor and unbalance appear desirable. In this way the capacity of the machinery can be determined with due regard given to working conditions of phase shift and unbalance. Both factors must be also included in wording the contracts for machinery. This will, unfortunately, introduce some new clauses in an already highly technical legal document.

As far as metering is concerned, it is possible to design meters to measure a power-factor of almost any kind of definition. However, separating the measurement of power-factor and unbalance permits the use of very simple schemes for measuring both, meters of standard types of construction could be used.

POSSIBLE DEFINITIONS

Single Factors—Several definitions have been suggested to represent the power-factor in a polyphase system and take account of unbalance. A single factor is then used for complete determination of the load conditions, as opposed to a double factor, one for measuring phase shift and the other for measuring unbalance. The following single factors may be mentioned.

$$\textit{Power-factor} = \frac{\textit{total watts}}{\textit{arithmetic sum of volt amperes}} \quad \cdots\cdots\cdots (1)$$

where *volt amperes* are determined by measuring the current in each phase and the *voltage* from each phase to an artificial neutral formed by three equal impedances. This definition has been tentatively suggested by the Joint Committee of the A. I. E. E. and N. E. L. A. as one of two alternative definitions. It takes account of unbalance, though not on any scientific basis. Its main advantage is simplicity and ease of derivation.

$$\textit{Power-factor} = \frac{\textit{total watts}}{3 \times \textit{r.m.s. current} \times \textit{r.m.s. volts}} \quad \cdots\cdots (2)$$

where *r.m.s. current* is derived from the three measured values of current by taking the root mean square of the three values. *R.m.s. volts* are derived in the same way from the voltages, measured as in definition *1*.

This definition gives a value of power-factor which bears a definite relation to the losses in polyphase supply circuit; namely, the losses are the same as would exist with a balanced, in-phase load $= \dfrac{\textit{measured watts}}{\textit{power factor}}$ This is the same relation as exists for a single phase power-factor.

The chief disadvantage of this factor is its complicated derivation. Direct measurement of this power-factor would be very difficult if not impossible. However, meters to measure r.m.s. of three currents or r.m.s. of three voltages could be constructed.

Double Factors—The power-factor for this method of considering the problem disregards the effect of unbalance. A separate unbalance factor is advocated to measure the latter. Different ways of defining "power-factor" on this basis have been suggested. The results given are, however, nearly identical.

$$\textit{Power-factor} = \frac{\textit{total watts}}{\textit{vector sum of volt-amperes}} \quad \cdots\cdots\cdots\cdots (3)$$

This definition is variously referred to as vector power factor or Italian power-factor. It is the second alternative definition suggested by the joint committees. The vector sum of volt-amperes can be obtained by geometric construction, using volt amperes as vectors with the respective angles corresponding to angles of lead or lag in each individual phase. Fig. 1 shows the derivation of this power-factor for a particular case of unbalanced currents. It will be noticed that for a balanced voltage condition the current unbalance is completely disregarded. If, however, a voltage unbalance exists, the power-factor measurement is affected.

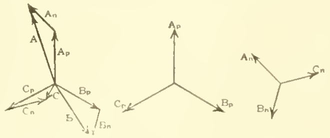


FIG. 2—THREE-PHASE SYSTEM WITH NEUTRAL OPEN CIRCUITED
Resolved vectorially into two balanced three-phase systems.

In order to understand the difference between this definition and the following, a brief outline of Mr. C. L. Fortescue's method of analysis will be given.

It can be shown that any three-phase system with neutral open circuited can be decomposed vectorially into two balanced three-phase systems, Fig. 2,—the one with the sequence of phases in one direction, the other with the sequence in the opposite direction. Thus the system A, B, C is decomposed into the system $A_pB_pC_p$, which may be called positive sequence, and $A_nB_nC_n$ which may be called the negative sequence. It can also be shown that this decomposition is perfectly definite for each particular case,—that is, only one combination of magnitudes and phases of this nature can satisfy each condition. It can be shown furthermore that the positive sequence is the only useful part in polyphase machinery. In fact, the negative sequence of currents is equivalent to a current flowing in a direction opposite to that of synchronous rotation of the machine. The result is a reduction in working torque of motors and additional losses in all polyphase machinery. In every circuit carrying currents of positive and negative sequence, the total losses equal the sum of losses due to the positive and the negative sequences. The total power and total reactive power are similarly equal to the algebraic sum of the respective values in the positive and in the negative sequences. In a balanced system, it will be found that the negative sequence disappears.

The above analysis of a three-phase system into a positive and a negative sequence resembles in many features the analysis of a single-phase condition into in-phase and out-of-phase components, or into real and reactive powers. It is evident that the negative sequence could be considered as the most correct and definite measurement of unbalance, which can be treated as independent of the balanced or positive sequence, but obeying the same laws. The total resulting condition is then the sum of the effect of positive and negative sequence.

$$\textit{Power-factor} = \frac{\textit{watts positive sequence}}{\textit{volt amperes positive sequence}} \quad \cdots\cdots\cdots\cdots \quad (4)$$

$$\textit{Unbalance-factor} = \frac{\textit{current negative sequence}}{\textit{current positive sequence}}$$

This definition of power-factor is different from definition *3* only in case of voltage unbalance. This is apparent by considering the volt amperes due to the negative sequence current and positive sequence voltage: the vectorial sum of these volt amperes is equal to zero. Hence only the vector sum of volt amperes of positive sequence current and positive sequence voltage determine the power-factor (3) and give a value equal to that of definition (4). However, if a negative sequence voltage is present, the negative sequence voltage and the negative sequence current give a value of volt amperes which add vectorially to the volt-amperes of positive sequence. Thus the value of power-factor by definition (3) will differ from that by definition (4). The latter definition disregards completely the effect of unbalanced voltage.

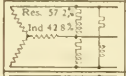
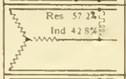
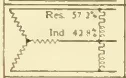
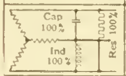
The unbalance factor gives a direct measure of unbalanced current. This definition is preferred to any other which would include the voltage unbalance to define the unbalance factor. In practice the voltage unbalance is small and it is really the current unbalance that is the origin of harmful effects.

As mentioned above, a distinction must be made between the unbalance created by a single-phase load, and that drawn from a polyphase machine by virtue of unbalanced voltage. Such discrimination could be achieved automatically by measuring the phase of negative sequence current with relation to negative sequence voltage.

$$\textit{Power-factor} = \frac{\textit{real power positive sequence}}{\textit{real power pos. seq.} + \textit{reactive power pos. seq.}} \quad \cdots\cdots\cdots\cdots \quad (5)$$

This definition is equivalent to definition (4) except stated in a different way. Definition (3) differs from it by the fact that it takes into account the real power of negative sequence and reactive power of negative sequence. The advantage of definition (4) or (5) over definition (3) is in the fact that it disregards the voltage unbalance completely. The unbalance condition can then be measured independently by unbalance factor.

TABLE I—POWER-FACTOR OBTAINED BY DEFINITIONS (1), (2), (3) AND (4) UNDER CERTAIN LOAD CONDITIONS

Load	1	2	3	4
	0 80	0 80	0 80	0 80
	0 694	0 566	0 80	0 80
	0 743	0.716	0 80	0 80
	0 358	0 346	1 00	1 00

It is possible to construct circuits which will measure power-factor and unbalance factor accurately according to definition (4) and use meters of almost standard construction. This would be, of course, of immense advantage on existing power networks, and with the manufacturers of measuring instruments. Easy conversion to meters suitable to this new definition is made possible. The practical difficulty in accepting this definition is that a new method of analysis of circuits must be introduced and accepted by a majority of interested parties.

In the matter of rate making, the following procedure has been suggested. The present method of charging for low power-factor should be complemented by introducing a similar charge for unbalance factor. It will be, of course, necessary to get the approval of technical authorities of government institutions before any such method could be universally accepted.

Table I illustrates by concrete examples the results given by various definitions under certain load conditions.

Three-Phase Current Limiting Reactors

M. E. SKINNER
Transformer Engineering Dept.,
Westinghouse Electric & Mfg. Company

THE COMMON form of current limiting reactor consists of a cylindrical coil of stranded copper cable supported in a fireproof structure. The usual practice has been to provide three single-phase reactors for each three-phase circuit to be protected. This arrangement lends itself toward carrying out the segregation of the different phases which is being advocated in modern bus structures. However, considerable space is necessary for the accommodation of three coils and, where the station was not originally laid out to provide for reactors, it is often impossible to find room for them.

The three-phase type of reactor will often offer an easy solution when other conditions are within the limitations of this type of coil. By a three-phase reactor is meant one in which the coils for all three phases are contained in a common structure and are so disposed as to take advantage of the mutual inductance between the various phases.

FUNDAMENTAL RELATIONS

Any conductor carrying current is surrounded by a magnetic field whose intensity diminishes as the distance from the conductor increases. If the magnetic field at any point is unidirectional and of constant value, no voltage will be induced in nearby conductors, unless they are moved about in this field. However, if the magnetic field is alternating, any conductor within its sphere of influence will have a voltage induced in it.

Energy is required to establish any magnetic field. In the case of direct current, the energy is expended in building up the magnetic field and is stored in the field until the circuit is broken, at which time it is returned in the form of the well-known "inductive kick." When the current alternates, the energy is stored in the magnetic field while the current is increasing and is returned to the circuit when the current decreases. The inductance of any circuit is a measure of the energy stored in that circuit. To make clear the distinction between self and mutual inductance, refer to Fig. 1. Here is represented a cross section of a conductor *a* carrying a certain current. The concentric circles represent the lines of force of the magnetic field produced by the current in *a*, the spacing of the lines representing roughly the field intensity. Certain lines concentric about *a* enclose conductor *b*; whereas, others are completed without encircling it. The self-inductance is a measure of the total field set up around *a*, neglecting the presence of *b*, and the self-inductive voltage is the voltage necessary to maintain the field. The mutual inductance of *a* on *b* is a measure of that portion of the field which is beyond *b*, and the mutual inductive voltage is the voltage induced in *b* by a current in *a*. Obviously, the closer the spacing between the conductors, the greater will be the mutual inductance between them.

Independent of *a*, conductor *b* may be carrying a current which will set up a field of its own, similar to that shown for *a*. The phase relationship between the self inductive voltage in *b* and the mutual inductive voltage due to the current in *a* will be the same as the respective currents in the two conductors.

Single conductors have been cited for the sake of clarity, but similar relations hold for groups of conductors or coils. Whether the mutual inductive voltages add to or subtract from the self inductive voltages will depend upon the relative polarity or direction of winding of the coils.

The simplest form of three-phase coil would obviously consist of three identical coils mounted one above the other and connected as shown in Fig. 2. The vector position of the self inductive voltages produced by three-phase currents flowing from A_1, B_1 and C_1 toward A_2, B_2, C_2 would be as shown by the vectors OA, OB and OC in Fig. 5. If the mutual inductive voltage between adjacent coils is taken as 20 percent of the self inductive voltage, (the mutual inductance between the extreme coils being negligible on account of the great spacing) its value and phase position is as shown by the vectors $A\text{-}M_{BA}$, $B\text{-}M_{AB}$, etc., and the resultant voltage will be the vector sum. The symbols and subscripts may be interpreted as follows:—$A\text{-}M_{BA}$ represents the mutual inductive voltage produced in phase A by a current flowing in phase B; $B\text{-}M_{AB}$ represents the mutual inductive voltage produced in phase B by a current flowing in phase A.

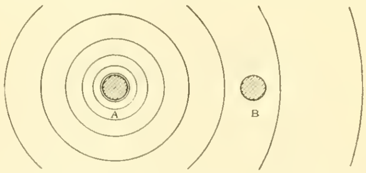


FIG. 1—LINES OF FORCE OF A MAGNETIC FIELD

It will be noticed in this case that the resultant voltage is less than the self inductive voltage. The resultants are not all of equal magnitude, and their phase position has been shifted from the 120 degrees relation. A comparison of Figs. 2 and 3 shows the result of reversing the middle phase. As in Fig. 2, the voltages are not equal and the phase position is shifted. In both cases the magnitude of the three resultant voltages may be made the same by increasing or decreasing the num-

ber of turns in the end coils. The phase shift however, will still persist.

In Fig. 4 is shown a three-phase reactor with one coil split into two equal and opposed halves, which constitute the end coils of the unit. By this rather novel scheme the resultant voltages in the three phases can not only be made to have equal magnitudes but their

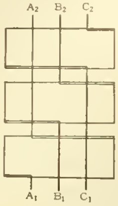


Fig. 2

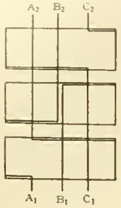


Fig. 3

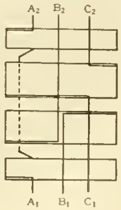


Fig. 4

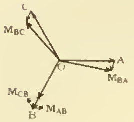


Fig. 5

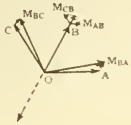


Fig. 6

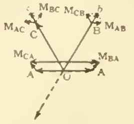


Fig. 7

FIG. 2—THREE SIMILAR COILS MOUNTED ONE ABOVE THE OTHER
FIG. 3—THREE SIMILAR COILS HAVING MIDDLE PHASE REVERSED
FIG. 4—ONE COIL SPLIT INTO EQUAL AND OPPOSITE HALVES WHICH CONSTITUTE THE END COILS
FIG. 5—VOLTAGE VECTORS FOR CONNECTIONS IN FIG. 2
FIG. 6—VOLTAGE VECTORS FOR CONNECTIONS IN FIG. 3
FIG. 7—VOLTAGE VECTORS FOR CONNECTIONS IN FIG. 4

phase displacement can also be maintained at 120 degrees, as shown in Fig. 7. The total voltage across phase A is M_{CA}-M_{BA}; that across phase B is o-b and that across phase C is o-c.

MECHANICAL FORCES MAKE REVERSED COIL NECESSARY

Independent of the addition of the voltage due to mutual inductance, a consideration of the mechanical forces which exist under short-circuit conditions would dictate that a 60 degrees relation between adjacent coils such as is obtained by the reversal of coils shown in Figs. 3 and 4 is the only practical one. The forces between magnetic fields always act in such a direction as to increase the total flux and therefore the total inductive voltage. The forces are therefore attraction between adjacent coils when they are connected as shown in Figs. 3 and 4 and are repulsion when the coils are connected as shown in Fig. 2. Since it is necessary to construct the coil structure of insulating and at the same time fire proof material, which invariably has poor tensile strength, it is imperative that the forces be compressional.

A typical three-phase reactor is shown in Fig. 8. This three-phase type has a very decided advantage over three single-phase coils in point of floor space, at the expense of a small increase in head room. For example, on a 6500 kv-a, 11 000 volt, three-phase, 60-cycle circuit, the space occupied by three single-phase coils of 3.5 percent reactance, including the necessary clearances, would be approximately 3 ft. 4 in. by 10 ft. floor space by 4 ft. 8 in. head room. One equivalent three-phase reactor would require approximately 4 ft. 5 in. by 5 ft. 2 in. floor space by 10 ft. head room. The ratio of the floor space is practically 3 to 2. The increase in head room is seldom a disadvantage, as it is always desirable to have enough headroom in any compartment to allow a man to pass without stooping, and usually the head room is fixed by other considerations than the height of the reactor. The saving in floor space may in some cases allow the installation of reactors in old and crowded stations, where single-phase coils would be out of the question. In point of cost, the three-phase type has only a slight advantage, as the cost of insulating between phases largely offsets the reduction in the amount of copper required.

SPHERE OF APPLICATION

Unfortunately, the sphere of application of this type of coil is somewhat restricted by certain limitations inherent in its construction. It is not feasible in reactors to use cables greater than about one-half inch in diameter without running up the stray losses very rapidly. There is thus a rather sharp limit to the amount of current which can be handled by a single cable. In the case of single-phase coils, it is possible to wind several cables in parallel in such a way as to make them divide the current equally. The method used to obtain equal current division among the various cables, necessitates bringing leads to the center of the coil. With single-phase coils, the leads can be brought out the top and bottom without crossing, but with a three-phase reactor the crossing of the leads within the rather restricted space inside the coils of any but reactors intended for low-voltage circuits would make it impossible to meet the rather severe tests which it is customary to apply to current limiting reactors. The tests applied to three-phase reactors by the Westinghouse Co. are as follows:—

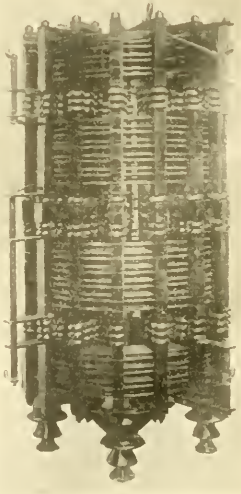


FIG. 8—A TYPICAL THREE-PHASE REACTOR

Line Voltage	Volts between Adjacent Coils at 60 Cycles for One Minute
Up to 2500	20 000
2500 to 7500	35 000
7500 to 12 500	50 000
12 500 to 17 500	70 000

Even without multiple cable windings it has been found almost impossible to meet these tests with the leads brought up through the center of the coils except on lines whose voltage is less than 5000 volts.

The fact that lead covered cables have about the same limitation of current capacity renders the three-phase reactor especially applicable to systems which distribute underground. A very interesting installation of this type of reactors is to be found at Cleveland, where a total of over 60 units have been in successful operation on the system of the Cleveland Electric Illuminating Company for something over two years. The rating of these coils is 119 kv-a., 200 amperes, 198 volts drop per phase on a three-phase, 60 cycle, 11 400 volt circuit.

Mechanical Construction of Water Wheel Driven Alternators

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A WATER WHEEL carrying full load runs with a normal peripheral speed of about half the spouting velocity of the water. At zero load, however, if the governor fails to operate, the speed of the water wheel will increase considerably. Hence, alternators driven by reaction-type turbines are designed for an overspeed of approximately 85 percent, and whenever possible are tested at the specified overspeed at the factory to insure satisfactory balance and to guard against defects in materials. Impulse wheels are usually designed with a lower ratio of normal peripheral speed to water velocity and may require that the rotors be built for overspeeds up to 100 percent.

An overspeed run is usually maintained for about one minute. Nothing is to be gained by running the machine for a longer period at maximum overspeed, as any defects would show up at once, and it does not seem good judgment to submit a machine to abnormal stresses any longer than necessary.

Rotors are designed to have a reasonable factor of safety throughout when running at the maximum overspeed. The shafts are carefully figured for stress and deflection, taking into account the critical speed. The spiders are pressed or shrunk onto the shafts with proper allowance to maintain a tight fit when running at overspeed.

SPIDERS

Small rotors up to about 55 in. diameter have spiders built up of 1/16 inch sheet steel laminations, as shown in Fig. 1. To insure the maximum possible uniformity of material, each lamination is revolved one pole pitch relative to the previous lamination during assembly. The dovetail slots receiving the poles are punched, and drifts are used in several of these dovetail slots during the assembly to assist in building up the punchings as evenly as possible. The laminations are held together axially by pressed-in rivets with heads spun over on each end. The bore and keyway for receiving the shaft are machined after the spider is assembled.

For rotors of medium size from 55 up to about 150 in. diameter, cast steel spiders are ordinarily used, as shown in Fig. 2. The castings are annealed and inspected for blowholes and other imperfections. If apparently satisfactory, they are carefully tested for ultimate strength, elastic limit, elongation and reduction of area by means of test coupons cast integral with the rotor spider. During the process of machining, the casting is again carefully inspected for seams, cracks and similar defects. The dovetail slots, by which the poles are held in position, are finished with milling

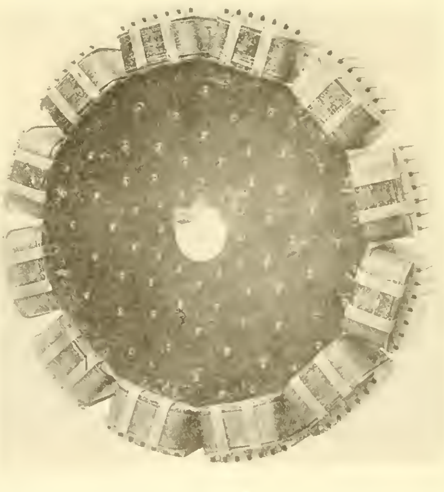

FIG. 1—SPIDER BUILT UP OF 1/16 INCH SHEET STEEL LAMINATIONS

cutters to secure the greatest degree of accuracy possible on the angles, fillets, etc. It would be cheaper to slot out these dovetails, but with this process there would be a possibility of imperfect fitting, sharp fillets and injurious tool marks.

For very high speeds, this construction would require a rim of such depth that the casting might be unsafe, since proper annealing would be difficult with ordinary foundry practice. In such cases a plate spider is resorted to, as shown in Figs. 3 and 4, which is built

up of hot-rolled open-hearth steel plates approximately two inches thick. Each slab from which the plates are cut is tested for physical properties by bending and tension tests, the test specimens being taken from the worst place on the slab. The individual plates are rough

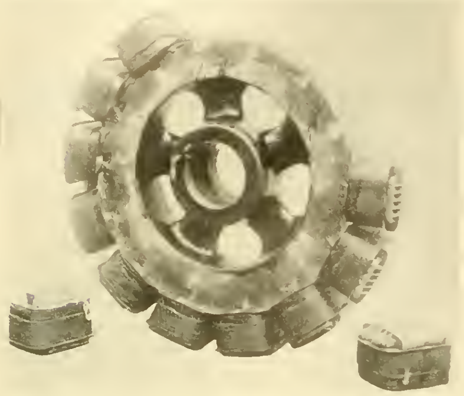

FIG. 2 CAST STEEL SPIDER FOR MEDIUM SIZE ROTORS

turned, and faced on the sides. They are marked with regard to the direction of rolling and the top of the slab and, while assembling, each plate is revolved one pole pitch from the preceding one. The plates are clamped together with throughbolts, a number of which are fitted into reamed holes.

For large spiders requiring deep rims, above 150 in. diameter, where thick rolled steel plates are not obtainable, or where the spider would be too large for shipment, a laminated spider rim is used, as shown in Fig. 5. These laminations consist of 1/16 in. sheet steel held to the cast wheel spider by dovetails fitted closely into milled dovetail slots on the end of the spider arms. The laminations are clamped together between heavy end plates with throughbolts of such a size as to make reaming unnecessary. The joints between the laminations are staggered in as many axial planes as practicable, to obtain the maximum possible strength.

Large spiders, greater than 180 in. diameter, must be split for shipment. Spiders with laminated rims are held together with bolts, the rim and poles being assembled at destination. Spiders with cast rims are fastened together with shrink links in the rim and bolts through the hub; such rotors can usually be shipped with most of the poles assembled at the factory.

FIELD POLES

Field poles are built up of 1/16 in. steel laminations held together either by rivets or by throughbolts which clamp the punchings tightly between end plates. The nuts of these throughbolts are countersunk into the end plates. The upper coil supports on the sides of the poles are used to hold the field coil ends in place against centrifugal force. They are either riveted to the pole tips or else are integral with the end plates. The lower coil supports are commonly made hollow so that metal can be poured into specially provided pockets when found necessary in order to secure proper static or dynamic balance. These coil supports are fastened to the spider by bolts and are provided with slots so that any radial play that may develop in any field coil, after the overspeed test, can readily be taken up. Each pole is provided with a dovetail which fits snugly into the dovetail slot on one side and leaves a space for the insertion of two tapered steel keys on the other side. The poles are fastened to the spider by driving the keys with a force sufficient to give a pressure somewhat greater than that due to the centrifugal force of the assembled pole and field coil during the overspeed test. The keys are then cut off flush with the spider rim.

A slight saving in rim depth may sometimes be obtained by using two or more dovetails per pole. This practice is not, however to be generally recommended, as the dovetails may become unequally loaded, due to slight inaccuracies in the machining or unequal driving of the dovetail keys. These disadvantages can be somewhat alleviated by partially splitting the pole body into as many sections as there are dovetails per pole.

FIELD COILS

Wherever possible, field windings are made of copper strap wound on edge, as this makes a strong coil. Where the voltage is too high to permit the use

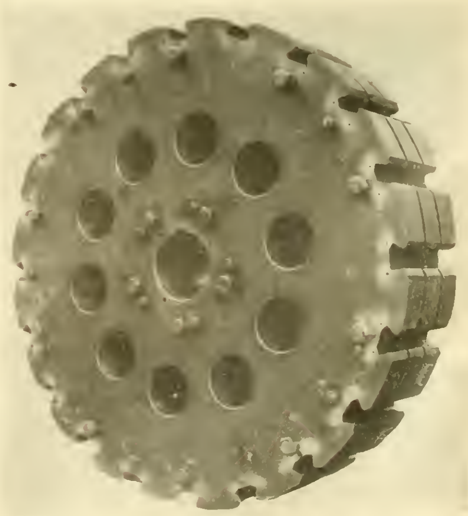

FIG. 3—PLATE SPIDER FOR HIGH SPEED ROTORS

of strap, insulated wire or ribbon is used, the latter being wound on edge. These coils are given a bakelite treatment which improves their insulation characteristics and makes them stronger mechanically. On high-speed machines, and especially on those with long cores,

it often becomes necessary to hold the coils in place with coil braces to prevent them from spreading out under the action of centrifugal stresses.

DOVETAIL TESTS

Extensive tests have recently been made to determine the comparative strength of different shapes of dovetails, as well as to see how the actual test results

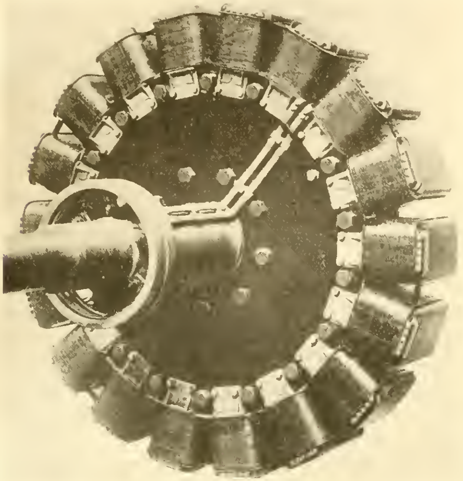

FIG. 4—PLATE SPIDER BUILT UP OF HOT-ROLLED OPEN-HEARTH STEEL PLATES

compared with the calculated strength of the dovetails and slots, and particularly to determine whether it is necessary to combine stresses in different planes in

FIG. 6—LAMINATED DOVETAIL FAILED BY BUCKLING

FIG. 7—LAMINATED DOVETAIL WITH END PLATES

FIG. 8—150 DEGREE LAMINATED DOVETAIL FAILED BY BUCKLING

FIG. 9—LIPS OF 60 DEGREE DOVETAIL SLOT TURNED UP

FIG. 10—150 DEGREE DOVETAIL SLOT

making calculations. For instance, should bending and tension be again combined with shear? Seven different pulling tests were made with samples of the dimensions shown in Table I, samples *1* to *5* being dovetails, and samples *6* and *7* dovetail slots. Samples *1* to *5* were built up of 1/16 in. steel laminations and samples *6* and *7* were made of hot rolled open hearth steel plate. The dovetails were pulled while engaged in dovetail slots of such proportions as to make the dovetails fail first. The dovetail slots were tested with dovetails of such size as to bring about failure of the slots without changing the form of the dovetails. Check tests were made on regular tension test pieces which were cut from the edges of the plates of which the dovetail slots were made. The elastic limit was determined by an extensometer. From these tests the following conclusions were drawn:

a—There was no marked difference in strength per running inch between the 0.75 in. long dovetail and the ones

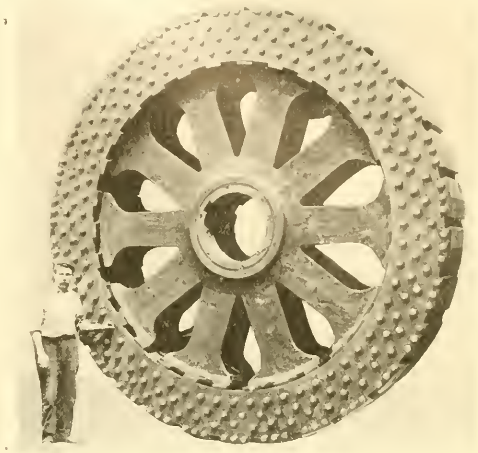

FIG. 5—LAMINATED SPIDER RIM BUILT UP OF 1/16 INCH SHEET STEEL

of 1.5 in. length. The test results can, therefore, be considered as representative for dovetails and dovetail slots of greater length, such as are ordinarily used in practice.

b—All punched dovetails, without end plates, failed by buckling, as shown in Figs. 6 and 8. There was no difference in strength between the one rivet and two rivet dovetails. The dovetail with end plates failed by tearing, as shown in Fig. 7. It began to yield with about the same pull as the dovetails without end plates.

c—The results obtained compared closely with calculations, and showed that the assumed plane of greatest stress was correctly chosen, and that stresses in planes at different angles, such as bending and shear, should be combined in order to get the maximum resultant stress

d—There was no apparent difference in strength between the two shapes of dovetails. For a given pull the 60 degree dovetail takes up approximately 25 percent less depth and about the same amount more in width than the 150 degree dovetail. Thus it was thought best to retain

the present standard shape, namely the 60 degree dovetail, especially since the 150 degree shape has certain disadvantages, such as narrower keys and smaller fillets, as well as the required centering of the poles circumferentially.

SPECIAL DESIGNS

Rotors of somewhat higher peripheral speeds can be built by resorting to the use of removable pole tips. In

TABLE I—DIMENSIONS OF TEST DOVETAILS AND SLOTS

Sample	Degrees	Depth In.	Width In.	Length In.	Rivets	See Fig.
1	60	2	3.5	1.5	1	..
2	60	2	3.5	1.5	2	6
3	60	2	3.5	1.5	End Plates	7
4	60	2	3.5	0.75	1	..
5	150	2⅞	2⅞	1.5	2	8
6	60	2	3.5	1.5	..	9
7	150	2⅞	2⅞	1.5	..	10

this design the rotor spider and pole bodies are integral, and are made of one solid steel casting, or several cast or forged slabs, or of the required number of rolled steel plates properly bolted together. The pole tips can be held on in various ways. The most common arrangement is that shown in Fig. 11, where the tips are fastened to the pole body by a number of screws or bolts, which are sometimes made of nickel steel. In Fig. 12 is shown a special arrangement in which the pole tip consists of a number of steel plates which are inserted into recesses in the outer part of the plates which form the spider and pole bodies. These pole tips are held to the pole bodies by throughbolts. Another method of fastening the pole tips to the pole bodies is

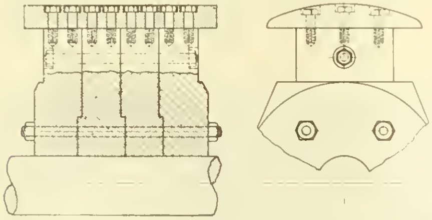

FIG. 11—POLE TIP FASTENED TO POLE BODY WITH NICKEL STEEL BOLTS

shown in Fig. 13. For this arrangement the pole body must be either round or square or nearly so. The pole tip is provided with a very course thread of a diameter about equal to two-thirds of the diameter or width of the pole body. It is either screwed into the pole body, as illustrated in Fig. 13, or is provided with a tapped hole and screwed over the pole body, the pole tips in this case forming part of the body. A laminated outer pole face may be used with the construction shown in Fig. 13, which is one solid piece of steel, but this is not possible with the poles shown in Figs. 11 and 12, which are

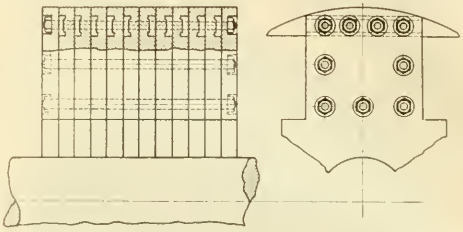

FIG. 12—STEEL PLATES OF POLE TIP INSERTED INTO RESESSES OF BODY PLATES

made up of steel plates. This pole face may be fastened to the solid part of the pole tip by dovetails, as shown in Fig. 13.

All these constructions are considerably more complicated and consequently more expensive than the ordinary designs with dovetailed poles. They also require more machining of a special nature and must, therefore, undergo more painstaking inspection. In the case of steel castings or thick cast slabs, the danger of faulty material remaining undetected is particularly great, on account of the large size and intricate shape of the castings involved. This danger is, of course, lessened in designs using forged slabs or plates, which

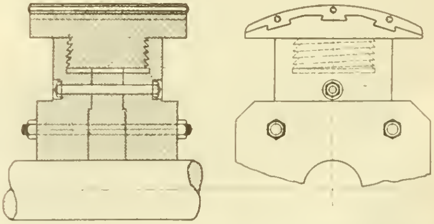

FIG. 13—POLE TIP SCREWED INTO POLE BODY

involve, however, much more machining. These designs have been used abroad more frequently, probably on account of the greater amount of skilled help available at reasonable prices there.

Typical Relay Connections

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Westinghouse Electric & Mfg. Company

During 1908 and 1909 a series of articles was published in the JOURNAL on "Meter and Relay Connections" by Mr. H. W. Brown. This series has been so widely useful that it was considered advisable to revise it, in view of recent developments, in a series of articles which would represent the best modern and up-to-date switchboard practice. As it was hardly possible for an author to revise the work of another done a decade previously, the result has been an entirely new series of articles on this important subject. The revised articles covering "Alternating-Current Switchboard Meter Connections," which were prepared by Mr. J. C. Group, were published in the JOURNAL during 1920. With this issue is begun a series by Mr. Lewis A. Terven on "Relay Connections" which covers the more common applications of this important piece of switchboard apparatus. In general Mr. Terven employs the same conventional representations for switchboard equipment and the same assumptions with regard to polarity, etc., that were used both by Mr. Brown and Mr. Group, and these are not repeated here, as they are given in full in the JOURNAL for January 1920. (Ed.)

A SHORT-CIRCUIT or other electrical disturbance arises too rapidly for a switchboard attendant to operate switches in time to prevent serious interruptions of service and the possibility of heavy damage to the generating and transforming equipment. Some means is necessary, therefore, of automatically clearing the system of such disturbances without the intervention of the operator. Circuit breakers for large modern power stations are so bulky that a large force is required to actuate them. A relay is, therefore, necessary between the circuit in which the trouble occurs and the circuit which provides the power for actuating the circuit breaker mechanism.

To clear an electrical disturbance on a large system with the minimum interruption of power supply, it is essential that certain circuit breakers should operate in a definite sequence, requiring a delayed action in the relay, which may amount to several seconds, and yet must be capable of adjustment to within a small fraction of a second. It is further desirable that a signal of some sort should inform the switchboard attendant of the automatic action that has taken place, in order that he may restore complete service as promptly as possible. Relays are also necessary for a variety of automatic functions involved in normal operation.

The relay is thus one of the most important pieces of switchboard apparatus. It can be built in a variety of forms and is adapted to a wide variety of applications. The purpose of this article is to set forth the use of protective and other similar relays and to give diagrams illustrating the methods of relay installation. It is frequently advisable to show relay connections as seen from the front of the instrument, because many relays are mounted on the rear of the switchboard, upon bases provided for the purpose, and when connecting the switchboard, the workman should have a front connected diagram of the relays upon a rear connected diagram of the switchboard proper. A dotted outline of the base indicates the shifting lines for the front and rear views. Descriptions of the actual relays themselves are not given, but can be obtained from manufacturer's catalogues or from various descriptive articles.

The subject will be divided into five very loose headings, treating first of direct-current relays, next of overload relays, then of reverse power and reverse current relays, sundry alternating-current relays, and finally, general applications. Since the field of one relay invariably encroaches upon the field of some other relay, a rigid classification would be difficult to make.

Direct-current relays and direct-current auxiliary relays are discussed first because they are used in many cases in connection with alternating-current switches, they are also much easier to understand, and consequently their treatment leads up to the comprehension of the more complicated alternating-current relay schemes.

DIRECT-CURRENT RELAYS

Fig. 1 illustrates a general utility circuit opening relay whose contacts are mechanically latched open upon electrical operation. The latch may be released by hand, or electrically by means of an unlatching coil, as shown. In this particular diagram the relay is used for bell alarm purposes, the operation being as follows:—Whenever the oil circuit breaker operates automatically, because of overload, current will be drawn from the positive bus through the unlatching coil to the relay bus and from there through the overload relay contact, trip coils and pallet switch to negative bus. The contacts of the bell alarm relay will close by gravity after being unlatched and the bell circuit is thereby established. The bell circuit is opened when the push button switch is pressed by the switchboard attendant, causing current to flow through the latching coil, this operation raises the contacts of the relay. The bell will not ring upon operation of the circuit breaker by means of the control switch. Furthermore, if other circuit breakers are installed, using the same bell alarm, the current required for tripping the circuit breakers automatically must pass through the unlatching coil, or from the positive bus to the relay bus. This feature is objectionable because circuit breakers are not all designed to take the same tripping current, and furthermore, in case of any open circuit between the positive and the relay bus, all of the circuit breakers on the

system would be without relay protection. These objections can be overcome by the use of a bell alarm relay whose unlatching coil is of the parallel type instead of requiring a series circuit as shown in Fig. 1.

In Fig. 2 such a bell alarm relay is shown with the unlatching or release coil across the direct-current control circuit. This relay is of the same type as the one just described with the addition of an auxiliary con-

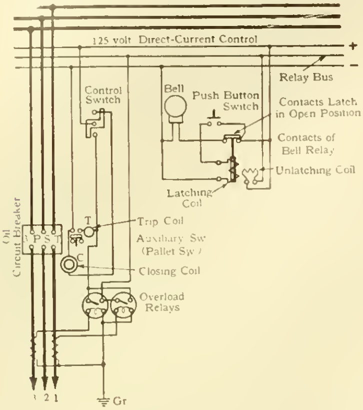

FIG. 1—CONNECTIONS FOR GENERAL UTILITY CIRCUIT OPENING RELAY

tact above the main contact, the auxiliary contact being closed when the main contacts are open and vice-versa.

In normal operation the main contacts of the bell alarm relay are open and the auxiliary contact is closed. Should an overload relay operate, causing the circuit breaker concerned to be opened, at the time of tripping the circuit breaker the overload relay also energizes a third contact, as shown in the enlarged diagram of the relay itself. Current from the positive control wire will then flow through the third direct-current contact of the overload relay, through a resistance to the release coil and through the auxiliary contact on the relay to the negative control bus, releasing or unlatching the relay plunger which falls to position, closing the main contacts and opening the auxiliary contact above. The bell circuit thus established will continue to ring until the reset coil is energized by means of the push button shown below the relay. It will be observed that the operation of the bell alarm relay is unaffected by the amount of current taken by the trip coil of the circuit breaker, and furthermore, that in case of failure in the bell alarm circuit, the automatic operation of any circuit breaker would remain the same as before.

The circuit breaker controllers used with this diagram are worthy of mention. The lamp cut-off contact is operated by means of the handle of the controller, which will remain mechanically in position when pulled out, opening the lamp circuit of the green light. The handle can only be pulled out when the circuit breaker is in the off position and thus the red light will already be out.

In case of the controllers for the double bus system, where it is required that the overload relays will operate either or both circuit breakers which may be closed, an additional segment is placed upon the controller drum, its position being such that when the controller is in the position of rest, i.e., free from the hand of the operator, this segment will connect the relay contacts to the circuit of the trip coil of the circuit breaker. Any number of circuit breakers can have their trip coils in parallel in this manner, and whenever manual operation is required, and the controller is moved over by hand, the contacts of the controller first clear the segment which connects the relay circuit with the trip coils, thus allowing any circuit breaker to be operated by hand without all the others of the system coming out at the same time.

Attention is also called to the small internal relay in the direct-current circuit of the alternating-current overload relay shown in the enlarged view. The trip current of the circuit breaker, flowing through the contactor switch coil, causes its plunger to rise until the three upper contacts are short-circuited by the disc as indicated. Clearly, once this relay closes its contacts, the removal of the alternating-current overload will have no effect upon releasing the plunger, because when the disc closes the upper contacts, the current in the direct-current circuit still flows through the contactor switch coil. This feature of the operation of the relay is not objectionable, because the trip circuit can be and should be opened by means of the pallet or auxiliary switch of

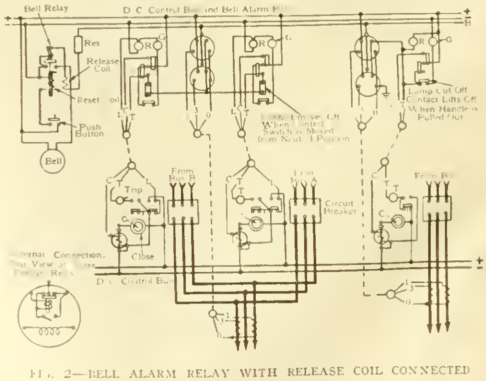

FIG. 2—BELL ALARM RELAY WITH RELEASE COIL CONNECTED ACROSS THE DIRECT-CURRENT CONTROL CIRCUIT

The lamp cut off contact is operated by the circuit breaker control switch. A small internal relay, in the direct-current circuit of the overload relay, prevents burning the overload contacts.

the circuit breaker, and all burning of the contacts of the overload relays is thus avoided. Furthermore, the internal contactor switch, due to its latching-in process, will prevent the burning of the more delicate overload

contacts, due to an overload which is barely sufficient to cause the contacts to close or perhaps to chatter.

If it is required to use separate control circuits for the circuit breaker belonging to the duplicate bus in Fig. 2, the extra segment on the controllers cannot be employed for the purpose, but auxiliary multicontact relays as shown later must be supplied, the object being to keep the control circuits apart. The amount of current drawn through the overload relay in order to trip a circuit breaker should be of sufficient magnitude to close the contactor circuit, but this requirement is easy to meet through design of the circuit breaker trip coils or through design of the contactor switch coil itself. The signal lamps may be connected to another circuit apart from the control bus, and for that reason the lamp cut-off contact is isolated from the main functions of the control switch.

The same type of relay shown in Figs. 1 and 2 is used in Fig. 3 for a trip free relay. In addition to the reset coil, the unlatching coil, the main contacts, and the auxiliary contact, a dashpot is shown which gives a time element to the opening of the main contacts when current flows in the reset coil. The object of the trip free relay is to render a plain automatic circuit breaker fully automatic.

The closing current of the oil circuit breaker, instead of flowing through the contacts of the control switch and directly through the closing coil to the control bus, flows through the coil of a control relay which, upon closing, allows current to flow from the control bus through the closing coil, thus closing the circuit breaker. The reason for the use of the control relay is that the amount of current taken to close most types of solenoid operated circuit breakers is too great to be

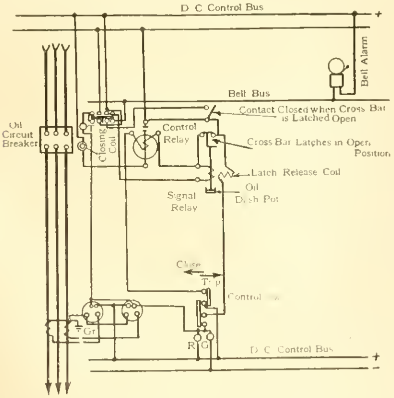

FIG. 3—BELL ALARM RELAY USED AS A TRIP FREE RELAY

interrupted successfully by the control switch, and furthermore, it is expensive to carry heavy conductors from the switchboard to the circuit breaker for closing purposes; whereas the current in the coil of the control relay is small. The control relay is usually mounted near the oil circuit breaker, frequently upon the mechanism of the breaker itself, and it is provided with a magnetic blowout coil which aids materially in interrupting the circuit of the closing coil. Even though the amount of current taken by the closing coil may not be high, the inductive character of the circuit is such that a very large spark or flash results upon in-

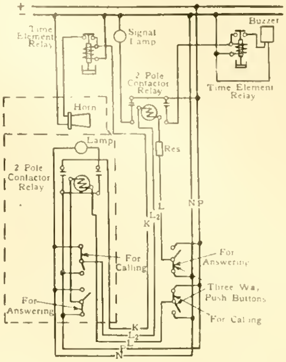

FIG. 4—TIME ELEMENT RELAY CONNECTIONS
For giving a definite time to a signal from a horn

terrupting this circuit, and for that reason control relays are used, even with rather small circuit breakers.

A circuit breaker is considered to be full automatic when the operator is powerless to keep it closed in case of an automatic tripping impulse. The trip free relay shown in Fig. 3 accomplishes this end by interrupting the closing circuit of the circuit breaker after the latter has been closed and latches the closing circuit open until the controller has been moved by the operator into the "trip" position, thus causing the trip free relay to unlatch and close its main contacts. Tracing the circuit through, the closing current for the circuit breaker is seen to flow from the positive bus through the control switch, the coil of the control relay, and the main contacts of the trip free relay, to negative. When the circuit breaker closes the pallet switches rise to the upper position, causing a current from positive to flow through the reset coil of the trip free relay and the main contacts to negative, which results in opening the main contacts after a definite time, determined by the setting of the dashpot shown in position at the bottom of the plunger of the relay. This relay opens its own circuit, leaving the reset coil disconnected from the circuit. Once the main contacts of the trip free relay are open it is impossible to pass current through the closing coil of the control relay, and hence the circuit breaker is subject to the action of the overload relays shown connected to the current transformers on the main line. Should the latter operate, positive control current will pass through the overload relay contacts, the trip coils, and the pallet switches (now in the upper position), to negative, thus tripping the circuit breaker. The alarm bell will be put into circuit from the positive to the bell, through the lower contacts of the right

hand pallet switch and finally through the auxiliary contact of the trip free relay to negative, the bell continuing to ring until the trip free relay is reset. This latter operation is performed by moving the controller into the trip position, which causes positive control current to pass through the latch release coil to negative, allowing the main contacts of the trip free relay to close.

Should the circuit breaker be tripped by means of the control switch the bell will not ring, because at the time the circuit is made through the tripping coil, the circuit is also established in the latch release coil of the trip free relay and, due to the difference in inertia of the apparatus concerned, the trip free relay will operate before the circuit breaker throws its pallet switches into the open position. In this diagram the red and green lights both burn through the trip coil of the oil circuit breaker. This arrangement has been found satisfactory, as the small drop in the trip coil does not affect the brilliancy of the lamps appreciably, nor is the current of the lamps of sufficient magnitude to trip the circuit breaker. However, should the circuit breaker be closed and a short-circuit occur in the filament of the red lamp, the circuit breaker will have full control voltage impressed upon its trip coil. The chances of such an occurrence are very remote, and are not usually guarded against, except where absolute continuity of service is desirable. In such a case, separate lamp wires are run between the switchboard and the circuit breaker, or a resistance is used in series with the lamp.

In Fig. 4 this same useful relay is shown connected for giving a definite time to the blast from a horn for signal purposes. Thus, should the operator from the switchboard gallery push a button notifying the attendant on the floor of incoming signals, the horn would give a definite blast, the relay opening the circuit of the horn after the time interval had elapsed, although current would still flow in the reset coil of the relay. Upon pushing the three-way switch in answer to the switchboard attendant, the main floor operator resets the relay of the horn and at the same time energizes a similar relay, which rings a buzzer in the switchboard gallery, notifying the switchboard operator that the signals have been observed.

Voltage Relations in Direct-Current Machines

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WITH the ever increasing voltage now being used in direct-current practice, the importance of a careful analysis of the voltage relations in all classes of direct-current apparatus becomes of more and more importance. Very often a direct-current machine is insulated with little regard to the potential difference between parts, other than to ground or between single coils.

The following investigation covers only the more common types of winding, but the application of the discussion and formulae to special cases may easily be made.

VOLTAGE TO GROUND

The voltage to ground for any type of direct-current machine needs little comment, except in so far as grounded or ungrounded circuits are concerned.

Grounded Circuits—On grounded circuits, the maximum voltage to ground is the total voltage of the apparatus. If two or more machines are connected in series, as on the 1200, 1500 or 3000 volt railway motors, then one machine will be constantly subjected to the total voltage at the maximum point, while the others will normally have only half the total, though under certain conditions, such as surges, starting, etc., this value may be exceeded.

Ungrounded Circuits—On an ungrounded circuit, the potential difference between the terminals may be considered as half positive and half negative, the grounded point being at zero potential. This being true, the voltage to ground on an ungrounded circuit will be one half of the terminal voltage. But even if the circuit becomes grounded in one place, there will only be a momentary flow of current due to the capacity of the circuit. However, the moment an ungrounded circuit grounds at one point, it then has all the characteristics of a grounded circuit. A more detailed explanation of ungrounded circuits will be given under voltage relations in field coils.

NOMENCLATURE

Turn—This will be best understood by reference to Figs. 1 to 4 inclusive.

Single Coil—This has an electrical significance and includes all the turns between commutator bars for a multiple winding or the number of turns between bars divided by the number of pairs of poles for a two circuit or series winding.

Complete Coil—This has a mechanical significance only and includes all the single coils which are insulated together from ground.

VOLTAGE BETWEEN TURNS

The voltage between turns is equal to the total volts divided by the number of turns in series. For a multiple winding

$$V_t = \frac{V_1 \, P \, K_v}{C \, T_s} \qquad (1)$$

Or for series winding.—

$$V_t = \frac{2 \, V_1 \, K_v}{C \, T_s} \qquad (1a)$$

Where

V_t = Maximum volts between turns.
P = No. of poles.
C = No. of commutator bars.
V_1 = Terminal volts.
T_s = Turns per single coil.
K_v = Factor to obtain maximum voltage.

In applying the above formulas, it is obvious that when T_s becomes equal to 1, V_t will be the volts between commutator bars, and formula (2) Figs. 1 and 2, developed for the voltage between single coils should be used.

VOLTAGE BETWEEN SINGLE COILS

The voltage between single coils for both lap and wave windings will be the same as the voltage between commutator bars.

$$V_s = \frac{V_1 P K_v}{C} \quad \ldots\ldots \quad (2)$$

Where, V_s = volts between single coils or between commutator bars.

It is evident from Figs. 5 or 6 that one single coil only is connected between commutator bars on the lap winding, while as shown by Fig 7, the wave winding has as many single coils in series between commutator bars as there are pairs of poles.

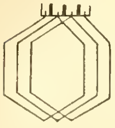


FIG. 1—SINGLE TURN LAP OR MULTIPLE WINDING

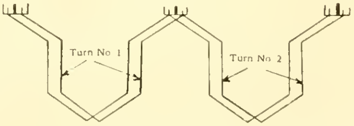


FIG. 2—SINGLE TURN WAVE OR SERIES WINDING

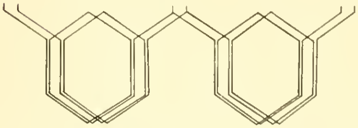


FIG. 3—TWO-TURN WAVE OR SERIES WINDING

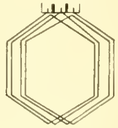


FIG. 4—TWO TURN LAP OR MULTIPLE WINDING

VOLTAGE BETWEEN COMPLETE COILS IN THE SAME SLOT

Pitch Winding—It is evident from Figs. 5 and 9 that the voltage between coils in the same slot for either a lap or wave winding will alternate from zero to approximately the maximum generated volts. If there is only one single coil per complete coil, and the brush covers only a little over one commutator bar, then the maximum voltage will be less than the generated voltage, but as the difference would ordinarily be small, it may be assumed that in all cases with pitch winding the maximum volts between coils in the same slot is equal to the generated volts. This maximum voltage between coils in the same slot will occur at the time the coils are in the neutral zone. In other words, at the time they are being commutated.

Chorded Winding—From Fig. 6 it is evident that the tendency of a chorded winding is to give a lower voltage between coils in the same slot for a lap winding. However, chording one slot with a reasonable number of slots and with an ordinary field form would give a potential difference very little different from the pitch winding. Comparison of Figs. 5 and 6 will show that the commutator bars spanned by the leads from the top and bottom coil are less with the chorded winding than with the full pitch winding. The voltage between coils would not decrease directly as the number of commutator bars, however, for, as shown in Fig. 8, a field form of a commutating pole railway motor, the first few bars on each side of the brush line have very little voltage between them, so that in the case of this motor the leads from the top and bottom coils could span a number of bars less than they would with a pitch winding without changing the integration of the curve to any great extent. It is evident, however, that if the winding is chorded down to such an extent that the total number of turns will need to be increased in order to generate the required voltage, the volts between coils in the same slot will decrease.

Fig. 7 shows that the leads from the top and bottom coil in the same slot in the case of a wave winding span more bars than the brushes, so that exactly the same results are obtained as in the case of a lap winding. It may be stated in general that with all ordinary chording, especially on railway motors, the maximum voltage between coils in the same slot will not be more than 10 or 15 percent less than the generated voltage.

VOLTAGE BETWEEN COILS ON ENDS

Pitch Winding—From Figs. 5 and 9 it is evident that the voltage between the upper and lower layer of coils at the ends changes from a maximum, the value of which is, in the case of pitch windings, always somewhat less than the voltage between coils in the same slot, to a minimum value of approximately zero. It will also be noted that the farther out from the iron, the less the voltage between layers. For example, in Fig. 5, the coils which cross at *a* connect to bars *3* and *6*, or a span of three bars. At *b* the coils connect to bars *4* and *6*, or a span of two bars. At *c* the coils connect to bars *4* and *5*, or a span of one bar. In the case of a wave winding the same thing occurs.

Chorded Winding—In a wave winding which is chorded to any great extent, the voltage between coils at the ends will first increase to a maximum, the value of which is never more than the generated volts, and then decrease to zero. This is shown in Fig. 7.

DOUBLE COMMUTATOR MACHINE

There are various ways of arranging the windings for a double commutator machine, but for the present discussion only that arrangement will be considered in which the first winding is wound and connected complete to its commutator before the second winding is put in place. With this type of winding, the top and bottom windings may occupy different percentages of

the slot area, as would be the case if one winding carries more current than the other. Referring to Fig. 12, in which T_1 = the top coil of the bottom or first winding, B_1 = the bottom coil of the bottom or first winding, T_2 = the top coil of the top or second winding and B_2 = the bottom coil of the top or second winding, the

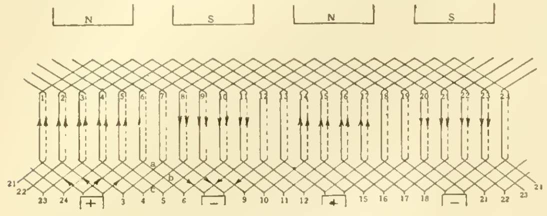


FIG. 5—FULL PITCH LAP WINDING

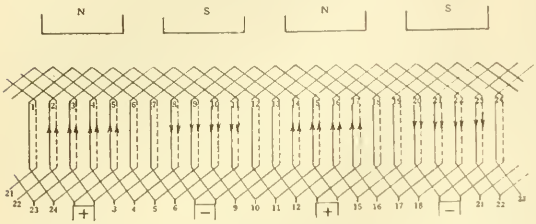


FIG. 6—CHORDED LAP WINDING

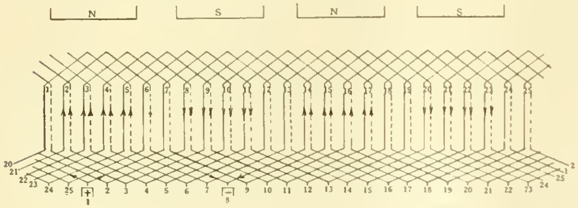


FIG. 7—CHORDED RETROGRESSIVE WAVE WINDING

voltage relation between T_2 and B_2 and between T_1 and B_1 has been discussed, but the voltage between B_2 and T_1 still remains to be investigated. A two circuit winding only will be considered, but of this type of winding two connections will be discussed, namely, progressive and retrogressive.

Both Windings Progressive or Both Retrogressive—The clearest conception of the voltage involved may be gained by the use of diagrams, so reference is made at once to Figs. 10 and 11, which show a 25 slot winding, with two coils per slot, and one single coil per complete coil. These two windings are supposed to be wound on the same core, with commutators at the opposite ends. The four poles of the machine are shown at the top of the figure and also at the bottom. It will be found by tracing out that the positive brush of one winding lies under the same pole as the negative brush of the other. In other words, B_2 is connected to the positive brush of one winding and T_1 to the negative brush of the other. This means, therefore, that the voltage between T_1 and B_2 at that particular point is the sum of the voltage across the two commutators if the windings are externally connected in series, but if the windings act as two separate generators, or as a generator and motor, the voltage between T_1 and B_2 at the point in question would only be the voltage across one commutator. The voltage between the other pair of brushes would, of course, be zero if the windings are connected in series, or the voltage across one commutator if the windings are separated. The foregoing will be more clearly understood by referring to Fig. 13, in which *A* is the winding of Fig. 11, while *B* is the winding of Fig. 10, shown connected externally in series. As an example, if the voltage across each winding is 600, then the voltage between + *a* and — *b* will be 1200 volts, and the coils T_1 and B_2 which successively come in contact with — *b* and + *a*, respectively, will have a potential difference of 1200 volts. The voltage between — *a* and + *b* is of course practically zero. From the foregoing it is evident that the voltage between B_2 and T_1, Fig. 12, when the two windings are in series, will vary from a maximum, the value of which is twice the voltage on one commutator, to a minimum, the value of which is approximately zero. If the two windings are not connected in series, but are entirely separate externally, as shown in Fig. 14, then assuming the same voltage per commutator as in the previous example, the voltage between + *a* and — *b* will be 600, and between — *a* and + *b* will also be 600. In other words, + *a* and + *b* are at the same potential above ground.

One Winding Progressive, the Other Retrogressive—It will be found by tracing out Figs. 9 and 10, which show a progressive and retrogressive winding respectively, that the positive brush of each winding comes under the same pole. This shows, therefore, taking into account the foregoing discussion, that B_2 and T_1 each connect to the positive brush of their respective windings at the same instant. This means, therefore, that the voltage between B_2 and T_1 is the voltage across one armature when the windings are

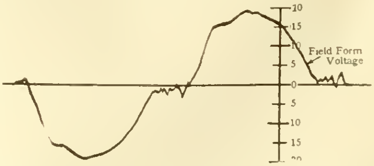


FIG. 8—FIELD WAVE FORM OF COMMUTATING POLE RAILWAY MOTOR

connected in series, as will be noted from Fig. 13. Or, using the same voltage per winding as before, the voltage between + *a* and + *b* is 600 and between — *a* and — *b* is also 600. The voltage between B_2 and T_1 is, therefore, constant and equal to the voltage across one

winding. If the windings are not connected externally in series, but are as shown in Fig. 14, the voltage between $+a$ and $+b$ is zero and between $-a$ and $-b$ is also zero. The case in which the voltage across the two commutators is unequal will not be discussed, as the voltage relation will be evident from the foregoing.

FIELDS

Series Wound—If the main and commutating fields in a series wound motor, which will be considered

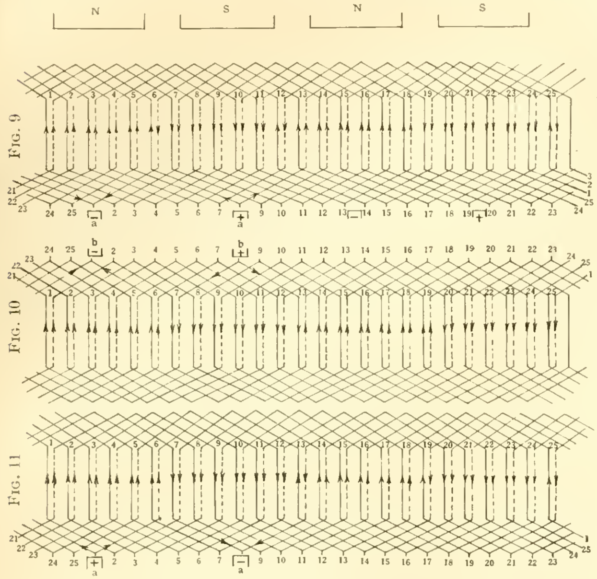


FIG. 9—FULL PITCH PROGRESSIVE WAVE WINDING
FIGS. 10 AND 11—FULL PITCH RETROGRESSIVE WAVE WINDINGS FOR DOUBLE COMMUTATOR MACHINE

on grounded circuits only, are connected on the line side of the armature, then the voltage to ground on the field coils is full line voltage, except for a few volts drop due to resistance of the coils themselves. If, on the other hand, the coils are connected on the ground side, they are normally only a few volts above ground. However, it has been found on railway motors of the series type that on sudden applications of voltage the fields absorb approximately 50 percent of the applied voltage, which, of course, means that some of the coils have a voltage to ground of one half the applied voltage.

Compound Wound Ungrounded Circuits—On an ungrounded circuit, no matter on which side of the armature the series field coils are placed, the voltage to ground may be considered as one half the generated or impressed voltage, as explained for the general case of ungrounded circuits. The shunt coils will bear the same relation to ground as the series, and hence the middle point of the shunt-winding may be considered as being normally at ground potential. This point is more clearly shown by Fig. 15. The voltage between point a on the series field and point b is, for the example considered, 500 volts, but point a is insulated from ground by insulation h and point b is insulated from ground by insulation k. The condition may, therefore, be illustrated by Fig. 16, in which a familiar problem in electrostatics will be recognized. Without going into the theory, which is discussed in most text books on the subject, it is sufficient to say that the potential gradient, or volts per mil in the insulation, will distribute inversely as the specific inductive capacity of the insulating material. This means that if insulation h and k are of the same material and of the same thickness, the voltage to ground at points a and b will be one-half the applied voltage. Referring again to Fig. 15, the voltage between point f on the shunt field, and point d on the shunt field is 500 volts, and the voltage to ground, of points f and d from analogy to the explanation given for the series field, will be one-half the applied voltage. As there is a uniform voltage drop through the shunt field, the difference of potential between e and f or between d and e will be one-half the applied voltage. This gives, therefore, assuming again uniform material and thickness of insulation g, zero voltage to ground at point e. The voltage to ground on a shunt winding, therefore, varies from a maximum of one-half

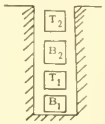


FIG. 12—ARRANGEMENT OF COILS IN SLOT OF DOUBLE WINDING MACHINE

applied voltage down to zero.

Voltage Between Shunt and Series Coils—From Fig. 15, point a on the series and point f on the shunt field are obviously at the same potential, but the voltage between point c on the series and point d on the shunt is the applied voltage less the IR drop in the

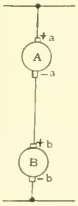


FIG. 13—SERIES CONNECTION FOR DOUBLE WINDING MACHINE

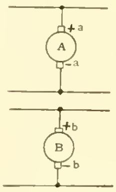


FIG. 14—PARALLEL CONNECTION FOR DOUBLE WINDING MACHINE

series field which, in most cases, is a very small percentage of the whole. Therefore, for practical considerations, the voltage between the shunt and series windings varies uniformly from zero to approximately full applied voltage.

Voltage Between Layers of Series Coils—If the series coils are wound in two or more layers, as is the case with the majority of railway motor field coils, the maximum possible voltage between layers under normal conditions will be the *IR* drop in the coil. Under sudden changes in load or application of voltage this voltage may be much higher, and may reach a point such that the fields absorb fully one-half the applied voltage, in which case the maximum voltage between layers could be expressed by the following formula:—

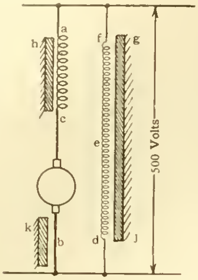


FIG. 15—COMPOUND-WOUND MACHINE UNGROUNDED

$$V_1 = \frac{V_t}{C \times L} \quad \ldots\ldots\ldots\ldots \quad (3)$$

Where,—

V_1 = volts between layers.
V_t = total volts absorbed by series field.
C = No. of coils.
L = No. of layers per coil.

The above formula is general and applies under all conditions. If the field coils are connected externally in series, the maximum possible voltage between layers will then be much higher than is the case if the layers of each coil are connected in series. Fig. 17 shows four two-layer fields connected internally in series. Fig. 18 shows the same field connected externally in series in one way and Fig. 19 with a different external connection. The voltage between the layers of all coils connected as in Fig. 17 will be the same as explained before, and is given by formula (3). The voltage between layers of coil *1* in Fig. 18 will be, of course, the full absorbed voltage of the field which, as before stated, may, at times, be as high as one-half the applied voltage. The voltage between layers of coil *2* will be three quarters of the voltage, of coil *3* one-half, and of coil *4* one-quarter. This applies only to a four-pole motor or generator, but the voltage relation will be the same for any number of coils. The voltage between layers of coils when connected as shown in Fig. 19 will be less than the maximum of Fig. 18, and will be equal for all coils. The value will be one-half the absorbed voltage of the field. The connections shown in Figs. 18 and 19 are used in field control railway motors.

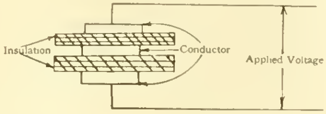


FIG. 16—SIMPLIFIED DIAGRAM OF VOLTAGE RELATIONS BETWEEN LIVE PARTS OF AN UNGROUNDED MACHINE

Voltage Between Turns—The volts between turns for any field, series, compound or shunt, is the voltage absorbed by the field, divided by the number of turns in series. If the shunt coil is wound in definite turns and layers, the highest voltage between any two given wires would be the voltage between layers, but if the coil is wound hit or miss, then the voltage between any two wires might be much higher than if it were wound in definite layers.

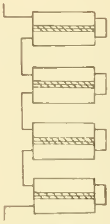


FIG. 17—COIL LAYERS INTERNALLY CONNECTED IN SERIES

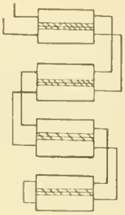


FIG. 18—COIL LAYERS EXTERNALLY CONNECTED IN SERIES

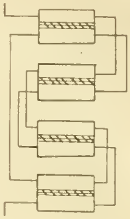


FIG. 19—COIL LAYERS EXTERNALLY CONNECTED IN SERIES

Voltage Between Main and Commutating Coils—The commutating coils are always on a different pole from the shunt or series coil, and so ordinarily there is no difficulty involved in insulating between them, but it is well to recognize that the voltage in some cases may be quite high. For example, if the series and commutating coils are connected on different sides of the armature, the voltage between them will be approximately full applied voltage. Or, an arrangement involving higher voltage still would be where a number of motors are connected in series, as on the 3000 volt direct-current railway system, with the fields on the ground side and a portion of the commutating coils on the line side or separated from the line by the absorbed voltage of only one motor.

The Liquid Slip Regulator

GUY F. SCOTT

IN MOTOR applications, such as for rolling mills and hoists, where the loads are intermittent and variable, high current peaks are produced by sudden application of load at the start of each operation. These high peaks are objectionable for the following reasons:—

1—They affect the voltage regulation on the lines.

2—When power is purchased on a maximum demand basis, these peaks result in increased costs.

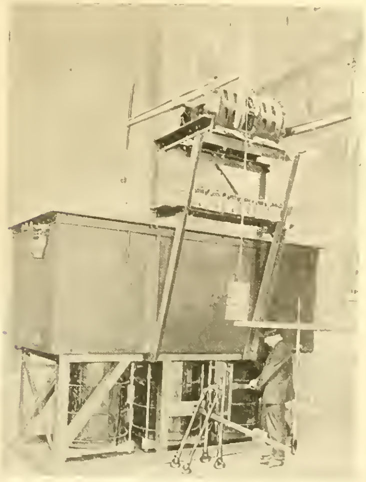


FIG. 1—AUTOMATIC LIQUID SLIP REGULATOR

3—There is difficulty in obtaining reasonable overload protection for the motor.

4—Heavy strains are introduced in windings and mechanical parts of the motor.

These peaks may be materially reduced by the addition of a flywheel on the motor shaft and a means of utilizing the stored energy of this flywheel when peak loads occur. This is accomplished with induction motors by increasing the slip of the motor at these periods through the introduction of resistance in the secondary circuits. This resistance may be in the circuit permanently or introduced by automatic slip regulators. The best known types of slip regulators are the magnetic contactor type with "notch back" relays, and the liquid type.

The liquid slip regulator, shown in Figs. 1 and 2, consists of a tank, to the bottom of which are attached three insulated cells, each containing a stationary electrode. The tank and cells are filled with an electrolyte (a solution of Na_2CO_3) which is obtained commercially as soda ash. The required density of this solution depends largely upon the characteristics of the individual motor and upon load condition during the starting period. For these reasons no definite density can be recommended, but in most cases the solution density giving best results is between one and two percent by weight. The operating temperature of the electrolyte should not exceed 80 degrees C, and in order to keep it within this limit, a set of coils is mounted in the tank through which cooling water is circulated.

Above each stationary electrode is suspended a movable electrode. These three movable electrodes are connected mechanically and electrically, and are suspended from balance arms which are attached to the shaft of a torque motor, mounted above the main tank. Adjustable counterweights are suspended from the outer ends of the balance arms. The primary circuit of the torque motor is supplied with energy from the secondary of a series transformer connected in the main circuit, as shown in Fig. 3, while the secondary receives constant excitation, so that the torque is proportional to the primary current.

The connections are such that the torque motor tends to rotate in the direction to separate the electrodes, and thereby introduce resistance into the motor circuit. As the current in the torque motor varies in a direct ratio and simultaneously with the current in the main motor, by the adjustment of counterweights and by changing the transformer ratio, the current at which the torque motor separates the electrodes may be fixed at any desired value.

The effects of the introduction of a slip regulator in the motor circuit are shown in Fig. 4. This is a typical recording wattmeter curve. The peaks taken by the motor when the regulator was not operating varied between 800 and 1200 kw, while with the slip regulator in service the peaks were reduced to a maximum of less than 800 kw, with an average of about 500 kw.

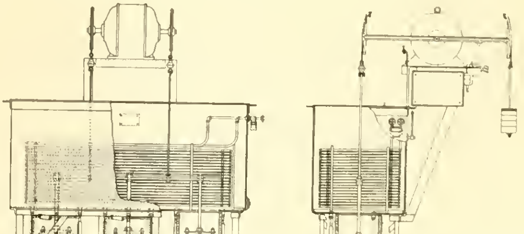


FIG. 2—CROSS-SECTION OF LIQUID SLIP REGULATOR

The liquid type slip regulator and the contactor

type function to produce the same effect. There is, however, the difference that, in the liquid type, the resistance change is gradual, whereas in the contactor

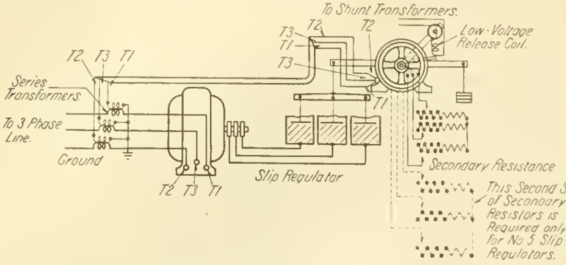


FIG. 3—REGULATOR CONNECTED IN MOTOR SECONDARY

type the changes are in abrupt steps, the number of which are limited. This difference is plainly shown in Fig. 5. Further, in the liquid type, the change in resistance follows the load closely; whereas, in the contactor type the peak current must be present before the relays can function. There is also a slight time lag due to the inertia of moving parts of the controllers. Again, these relays must be so designed that the resistance steps will be inserted at a high value of current and cut out again at a comparatively low value, so that the current rush caused by the short-circuiting of the resistance step will not be sufficiently high to cause the relay again to insert the resistance, for this would result in a short life of contacts due to successive opening and closing. This peculiarity of design in the relays results in the resistance being in the circuit longer, and consequently this type of regulator is less efficient than the liquid type. Another thing to be considered is the space requirement. The liquid type regulator, being water cooled will occupy considerably less space than types which use metallic resistance.

In operating, the liquid type slip regulator, after having been adjusted for the load requirements by making the proper transformer connections and by the finer adjustment with the counterweights, requires little attention other than an occasional inspection of electrodes and the cleaning of the tank and cooling coils. This has in some cases resulted in a tendency toward neglect of the apparatus, which should be carefully avoided.

For cleaning and inspection, it is advisable to have a pit, with sewer connections, beneath the regulator, of sufficient size to contain all the electrolyte. Facilities should be provided for either pumping this electrolyte back into the tank, or discharging it into the sewer. With these facilities the tank can be emptied, the electrodes inspected and cleaned, and the electrolyte returned to the tank, in a very short time. When this is done, it is advisable to leave an inch or two of the electrolyte in the pit, to be drained into the sewer together with any sediment that may have collected. This small loss of electrolyte should be replaced, and the proper level maintained by the addition of water through a valve provided in the cooling coils, and by the addition of sodium carbonate to restore its density.

The cooling coils can be kept free from scale by blowing compressed air through them frequently. For this purpose it is well to have a permanent air connection at the inlet end of the coils.

During the course of development of the liquid slip regulator, covering a number of years, experiments were made with electrode cells of various grades of earthen-ware. Because of a slow disintegration of the earthen-ware under the action of the hot soda solutions, and the effects of the sudden variations in temperature, the results with these cells have not been very satisfactory, and their use has been discontinued. Specially constructed cells of treated wood suspended by insulated hangers are now being used, with good results.

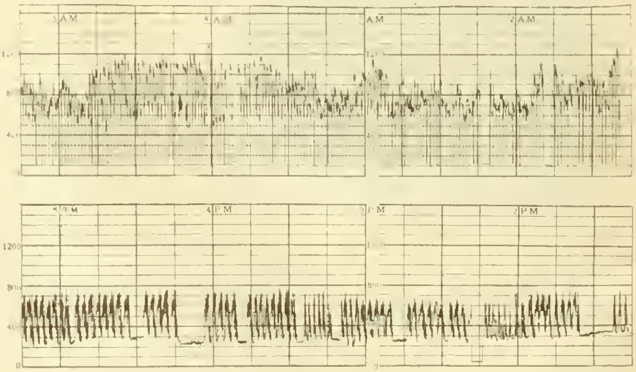


FIG. 4—WATTMETER RECORDS OF 600 HP. MOTOR DRIVING A BILLET MILL

The top record was made without the regulator. A comparison with the bottom record shows the effect of introducing a slip regulator into the motor circuit.

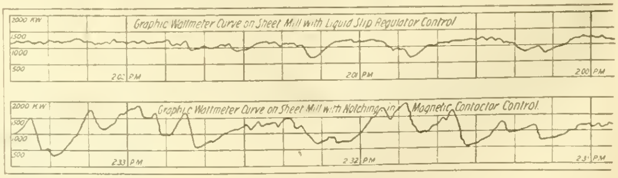


FIG. 5—COMPARISON OF LOAD CONDITIONS OF A 1500 HP. SHEET MILL MOTOR

Snow Fighting Methods

On the Electrified Section of the Chicago, Milwaukee & St. Paul Railroad

E. SEARS
Division Master Mechanic

IN ELECTRIFYING a railroad through the Rocky Mountains, and more especially through the Cascade Mountains in the northern states, the weather conditions must be carefully considered, as the temperature sometimes stays around forty to fifty degrees below zero for days at a stretch. Seasonal snow falls of thirty to forty feet are recorded in places by the weather bureau. A snow storm of only a few inches on the level may drift to many feet deep in some places, and cuts are sometimes completely filled with snow within half an hour after they have been opened by the rotary snow plows. With steam locomotives, such weather conditions are at times very serious, resulting in temporary suspension of service, particularly freight, on account of the reduction of steaming capacity or the freezing up of the locomotives. The severe cold does not, of course, impair the operation of an electric locomotive, but is to some extent beneficial. It has, moreover, been found in actual operation on the Chicago, Milwaukee & St. Paul Railroad that the heavy snow falls do not interfere with the electric trains nearly as much as with the steam trains, and that clearing the tracks of snow is easier with electric locomotives than with the steam locomotives.

FIG. 1—ROTARY SNOW PLOW

A moderate depth of snow, say four to five feet, unless it is heavily packed, and even greater depths extending for only a short distance, can be removed most easily by means of the wedge type snow plow. The Chicago, Milwaukee & St. Paul Railroad have a number of double mold board Barr plows of this type which are placed ahead of loaded ballast cars and driven at high speed through the snow by two or three locomotives. These are usually able to take care of the snow situation in the Rocky Mountains, as the snow does not usually attain as great depth in this territory as in the coastal ranges. When fighting snow in this manner the entire crew are continually wet from the snow which is melted by the heat of the locomotives. The flying snow fills every part of the equipment, and the quantities of snow which are necessarily shoveled into the fire box with the coal makes steaming difficult. A considerable gang of laborers with snow shovels is usually carried for use in emergencies.

FIG. 2—ROTARY SNOW PLOW PUSHED BY STEAM LOCOMOTIVE

For deeper snows the Chicago, Milwaukee & St. Paul Railroad have six rotary snow plows, which are used mostly in the Bitter Root and Cascade Mountain ranges. As will be evident from Fig. 1 the rotary snow plow is pushed ahead of the locomotive, and acts as a large auger, boring its way through the snow banks. The rotary wheel is about 12 feet in diameter. It is faced with knives that cut into the snow which is thrown by centrifugal force out of the chute at the upper part of the wheel housing. The wheel can be driven in either direction in order to throw the snow to whichever side of the track is desired. The blades are tied together in pairs, and when the direction of rotation is reversed, the centrifugal action reverses the

FIG. 3—ROTARY SNOW PLOW AT ROLAND, IDAHO IN THE BITTER ROOT MOUNTAINS

blades, so that they always cut in the direction of the rotation. They are strong enough to handle slides containing small tree stumps without sustaining any material damage.

The plow is equipped with a boiler and an engine which drives the rotary wheel. This engine and boiler are operated by an engineer and fireman in the cab of the snow plow.

The snow in the Bitter Root and Cascade Mountains often attains a depth of 15 to 20 feet in one snow storm, and there are times when these drifts are higher than the plow itself. The rotary plow can operate in drifts which are somewhat deeper than the plow itself, as the snow is thrown out with considerable force. When the snow is packed deeper than the rotaries can handle, short holes are bored into it with the rotary wheel, into which the tops or sides are broken by laborers.

The snow slides are the greatest enemy of the snow plow in the mountain district, as they cover the tracks to considerable depths; at times they catch a plow and bury it completely. Several times the entire crew have been caught in such slides, making it very difficult for them to dig their way out. In one case, one of the electric locomotives without a rotary plow attached, ran into a large drift and several visiting electrical engineers who were on the locomotive were entirely buried in the snow, which forced itself through the broken windows and filled the cab.

Prior to the electrification, as high as three or four steam freight locomotives were placed behind the rotary plow. Now the rotaries are handled by one electric locomotive and, inasmuch as each half of the present freight locomotives, when not coupled together, can be run as a separate unit, only one unit of the engine is sometimes employed, although in heavier drifts both units can be cut in, giving full power to push the snow plow. The tractive effort required to push the rotaries depends on the depth of the snow, and we have had no deep snows recently. Last winter we had no use for the rotaries at all.

The heavy snow falls do not interfere with the electrical operation over the mountain territory as much as they did with steam, since an electric engine will plow through snow where a steam engine will not go. The heavy snows have no bad effect on the overhead wiring. We are not subject to any heavy sleet storms in this section, but at times a very heavy frost collects on the two 4/0 copper trolley wires. With a pantagraph of the double shoe type, sliding on two trolleys whose hangers are spaced alternately, excellent current collection is obtained at all times and sleet and frost have not so far bothered us to any extent. Sometimes during heavy frosts, both pantagraphs are raised, the front one serving principally to clear the wires.

Experience indicates that snow fighting can be handled better with electrical equipment than with steam. The electrical equipment gives better speed control, as there is no difficulty in securing all the power desired and there is no opportunity for the freezing up of injector pipes, etc., on the locomotive, or the necessity of having to go back for water or fuel, except to meet the fuel and water demands of the rotary plow itself.

The only change necessary to adapt the rotary snow plow to use in the electrified territory was the attaching of a deflector on the upper part of the rotary hood, so that the snow and other material, when thrown out, would not come in contact with the power limiting and other wires. These are at such a height that a rotary, in its original condition, would throw the snow onto the wires and trouble was experienced from this cause when first operating the rotaries in the electrified section.

No doubt in the near future rotary snow plows will be built with electric motors instead of steam engines for electrified territory, and the old ones will be changed over for electric operation. The only draw back to operating the plow itself with motors is that quite often the rotary wheel will freeze, in which case it is necessary to have steam available to thaw it out. This could be overcome by using a small boiler similar to the ones which are now being used for heating the passenger trains.

Reminiscences of the Erie Electrification at Rochester

To the Editor of The Electric Journal:

Dear Sir:—The article on the Erie Railroad Electrification, published in the October number of The Electric Journal, is an excellent account of the pioneer single-phase steam railroad electrification in commercial service in the United States, and is naturally of especial interest to the present writer, because of his connection with it in the capacity of engineer-in-charge of the design and execution of the work which was carried out between September 1906, and June 1907, by the old engineering organization of Westinghouse, Church, Kerr & Company, which left its stamp upon so many large railway improvements throughout the country.

Mr. Hershey is not quite correct in stating that the New York, New Haven & Hartford, and the Boston & Maine single-phase electrifications were in successful operation at the time the Erie electrification was created. It is true that the former electrification had been in process of construction for a year or two and the engineering features of it naturally supplied some useful precedents in working out the details of the overhead construction on the Erie road, but the difference in the size of the jobs was so great that less than a year sufficed to do the preliminary engineering and installation for the Erie, and its successful and continuous commercial operation began on or about June 23, 1907, just about one week before regular

operation began on the New Haven. Therefore, it can justly be claimed that the Erie electrification was the first 11 000-volt, single-phase system to get into regular commercial operation on a steam railroad. The Hoosac Tunnel electrification of the Boston & Maine Railroad was not constructed until 1910.

Credit for the original suggestion of single-phase operation for the Erie, may be due to Mr. L. B. Stillwell and his organization, by whom, if the writer remembers correctly, this system was recommended to the management of the Erie rail road; but the contract for construction and equipment was placed with Westinghouse, Church, Kerr & Company. It is evident from Mr. Hershey's article that all the component parts of the original installation are still in service, with the addition of two motor cars and the supplementary steel trolley wire. In the summer of 1906, electric service of six-car trains was not contemplated as a regular feature of operation, but the fact that it is possible with two motor cars and four trailers is due to the careful analysis of the proposed electric service made at that time.

There were not more than five or six regular railway station stops in the 19 miles between Rochester and Avon; but in order to attract travel, the railway company specified that provision should be made for local stops by most of the trains, at every cross-road along the route. The carrying out of this provision is undoubtedly one of the factors that has made this electrification so popular with the public that it serves, and was the immediate cause of the 100 percent increase in its traffic during the first year of its operation. These cross-roads stops average about one mile apart and, as it was expected that the railroad trains would very frequently consist of one motor car and one trailer and it was judged that on frequent occasions such a train would be required to make all stops over the line, an equipment of four 100 hp motors was found necessary in order to be sure that the motors should at all times be equal to the most severe duty, with the 50-50 proportion of motor cars and trainers contemplated. It was also found that with the four-motor equipment, two trailers per motor car could be put on express runs with fewer stops. We thus discounted in advance the inevitable tendency of steam railroad men to load equipment to its limit as a matter of regular operation, by stating these limitations clearly and providing equipment that would always meet them; and the wisdom of an equipment of four 100 hp motors per motor car, as a matter of engineering foresight, has been demonstrated continuously from the very beginning, as is still attested by the review of operating records given by Mr. Hershey. The average figure of 79 watthours per ton-mile does not seem too large when it is recalled that this is a suburban rapid transit service with relatively frequent stops, quite different from a through service with long runs. The multiple-unit control, the pantograph trolley and all other auxiliary features of the equipment, functioned very well from the very beginning, and it would appear from the records that all parts of the car equipment are as satisfactory at this date as they were 13 years ago.

In view of this record, in an art which is supposed to be constantly improving and rendering obsolete the work of five or ten years previous, it would be interesting to get comments from professional valuation engineers as to the percentage of obsolescence that should be applied to this equipment, in computing its present day value.

The overhead trolley construction was the one tough problem in this electrification. Mr. Hershey is not quite correct when he says "At the time this installation was made, overhead construction was still somewhat in the preliminary stage;" though his qualification immediately following, that the catenary type of suspension was at that time experimental, is quite correct. For the benefit of the present generation of electric railway engineers, let it be stated that overhead trolley construction in general is not materially different from what it was 25 years ago, by which time the principles and the mechanical parts used, had pretty well settled down to their present standard forms. But in 1906 the catenary form of construction was only one or two years old, and most of the engineers who had to tackle it at that time had to set their own precedents, the Erie installation forming no exception.

In designing, purchasing and erecting the overhead equipment, mechanical ruggedness was kept constantly in view as the prime requisite, and the rigid fastenings between messenger and trolley wire were designed accordingly. It is quite true that, in the original installation, we had to take some chances with the effects of the differences of expansion and contraction between the steel messenger and copper trolley wire. These differences were somewhat accentuated by the fact that there is very little curvature in the railway line and that curvature is very gentle, so that there is less chance for the elasticity of the poles to let the wires come and go cross-ways of the track at curves, and thus ease off the longitudinal temperature stresses, as is the case on a crooked line.

During the early operation period it was necessary to pull the trolley wire considerably tighter than would have been the case had there been more frequent overlapping breaks in the trolley wire, or more curvature in the line. It is possible that a less rigid hanger rod between messenger and trolley would have eased the situation somewhat, but at that time we did not like to risk any element of flexibility that might cause wear on the galvanizing of the messenger cable. Looking back on the ruggedness of the methods then used, the writer confesses his apprehensions, at the time, of a great deal more trouble than ever happened. As it turned out the rigid, rugged type seems to have done pretty well for the traffic conditions prevailing on the Erie, for it was seven or eight years before it was found necessary to add the supplemental trolley wire. It should also be stated in this connection that the pressure for rapid completion of this contract was very insistent, because of the necessity for promptly heading off threatened competition from a cross-country trolley line that was then being promoted through the same region; and there was no time for experiments, or for the developing of refinements that were subsequently found possible on work of this character, such as were incorporated a year or two later on similar jobs.

The overhead work was insulated throughout with porcelain, as no [illegible] insulating compounds had then been perfected which would stand 11 000 volts in all kinds of weather. We tried one such compound for strain insulators, and for suspensions for use over yard tracks, but its failure was so prompt and so universal that we abandoned it, and substituted porcelain everywhere.

The tension rods for the trolley bracket arms were so attached to the pole as not to require boring of the pole near the top, in order to prevent access of moisture into the pole top, thereby lengthening its life. This refinement may have been considered expensive at the time, but the excellent record of durability shown by the chestnut poles has probably been assisted somewhat by attention to this detail. The catenary construction in terminal yards is supported by spans carried on steel poles of the tripartite type, designed stiff enough to require no back guying.

This system was erected and placed in operation at a time when the so-called "battle of systems" was raging most fiercely. Being a single track affair on a subsidiary division and not in any way conspicuous, the Erie electrification has been plugging along for 13 years without arousing much widespread interest, although from the very start its operating success was such, both from the standpoint of reliability in public service and in meeting financial expectations, that the railway officials used to express the wish that the whole division were electrified instead of only a small part of it. The electric motor cars were used to pull derailed steam locomotives on to the track, even in the earliest years of electrification, and probably do it yet upon occasion. The writer was once told of the indignant refusal of the railway company to listen to a proposal from an outside source, that the single-phase system be replaced by a high-tension direct-current system.

Unquestionably the continued operating success of this system is largely due to the faithful and intelligent supervision it has had from Mr. Thurston, who has been connected with the system since its installation; and to the co-operation which he has effected between two sets of employees trained respectively in the schools of steam and electricity.

A complete description of the Erie installation was prepared by the writer and published with illustrations in the "*Electric Railway Journal*" during October, 1907, giving considerable detail with regard to the features of the car equipment, trolley construction, car house and substation. Mr. Hershey's article, written thirteen years later, is a sufficient answer to the past and present criticisms of the efficiency of the single-phase system under conditions similar to those obtained on the Rochester division of the Erie Railroad, which is a typical single-track line of physical characteristics identical with many of the steam railroad trunk lines of the country. It is also an object lesson in railroad economics, as an example of the wisdom of the Erie management in preventing a waste of new capital in a competitive road, by seizing the opportunities of electric motive power, in order to increase the capacity and usefulness of an existing line of steam railroad.

W. Nelson Smith,
Consulting Electrical Engineer,
Winnipeg Electric Railway Company.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1946 — PARALLELING TRANSFORMERS—In an industrial plant with two banks of three 500 kv-a, single-phase, 13 200 to 2200 volt transformers connected delta-delta to separate loads on a three-phase, three-wire system, considerable trouble is experienced from sudden heavy short overloads. If all the load could be fed from one bus the diversity factor would decrease this trouble. The transformers are of the same design and are guaranteed to operate successfully in parallel with each other. What is the general practice in this regard in plants which do not experience our trouble? Would it be good practice in our case to operate the transformer banks in parallel. If paralleling is out of question, what is the best form of protection? Is it generally considered necessary for transformers of this capacity to use balanced relays (in addition to overload relays) to protect against trouble in the transformer itself? If not, what form of protection would you recommend? Is it possible to operate two transformers on open delta in parallel with three on closed delta? W.A.D. (ONTARIO)

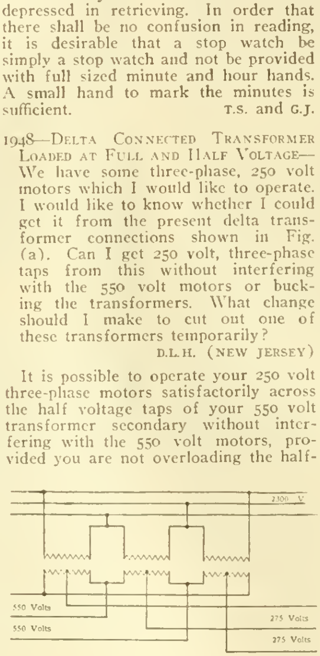
Industrial loads of this size are generally supplied from one bus. There should be no difficulties experienced in operating these loads from the same bus. It is not generally considered necessary to protect transformers of this capacity with balanced relays. Sufficient protection should be produced with automatic oil circuit breakers in both the 2200 volt and 13 200 volt lines with short time setting on the 2200 volt circuit breakers. It is possible to operate an open delta bank of transformers in parallel with a delta bank but the division of load is not very good: for instance, the transformer in the delta bank that is connected to the open phase of the V bank will carry 130 percent load, when the other transformers are carrying normal load. See article on "Delta and *V*-connected Transformers in Parallel" by E. C. Stone, in the JOURNAL for April, 1910, p. 304. J.F.P.

1947—RELATIVE MERITS OF STOP-WATCHES—Please discuss the essential characteristics of a good stop watch for use in electrical tests. M.M. (ILLINOIS)

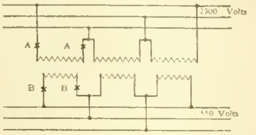
A stop watch consists, essentially, of two main members—the watch proper or time-keeper, and the controlling device or starting, stopping and retrieving mechanism. The watch proper need not be an exceptional time-keeper, but it is important that it be of such material and workmanship as will ensure ruggedness and positive, regular action. The controlling device is, by far, the more likely to give trouble and, therefore, is the member that should be given particular consideration in selecting a stop watch. Controlling devices employ either friction drive or gear drive. Gear drive is generally more positive and reliable, providing there are sufficient number of gear teeth so that there will be a delay of not over one-tenth of a second in starting the mechanism, therefore, if all other things are equal, this class is to be preferred. In any case, to be reliable, there must be no tendency to slip or lag in starting, drift or creep when stopping, and the hand or hands must be returned positively and definitely to zero when the stem is depressed in retrieving. In order that there shall be no confusion in reading, it is desirable that a stop watch be simply a stop watch and not be provided with full sized minute and hour hands. A small hand to mark the minutes is sufficient. T.S. and G.J.

1948—DELTA CONNECTED TRANSFORMER LOADED AT FULL AND HALF VOLTAGE—We have some three-phase, 250 volt motors which I would like to operate. I would like to know whether I could get it from the present delta transformer connections shown in Fig. (a). Can I get 250 volt, three-phase taps from this without interfering with the 550 volt motors or bucking the transformers. What change should I make to cut out one of these transformers temporarily? D.L.H. (NEW JERSEY)

It is possible to operate your 250 volt three-phase motors satisfactorily across the half voltage taps of your 550 volt transformer secondary without interfering with the 550 volt motors, provided you are not overloading the half-



(a)



(b)

FIGS. 1948 (a) and (b)

voltage taps. If half the rated kv-a of the bank is connected to the full voltage leads as shown in Fig. (a) an additional load of 32.5 percent of the normal rating may be connected to the half voltage leads, assuming that the two loads have the same power-factor. When using only a three-phase load, connected to the half-voltage taps, the transformers will give half their kv-a output without overheating. With your present transformer connections, it is quite simple to cut out any one of the three transformers and still have a three-phase system. By disconnecting the primary terminals of any one of the transformers at points A, A′ as shown in FIG. (b), and the secondary at points B B′ the remaining two transformers will be connected open delta. M.M.B.

1949—ADVANTAGES OF ELECTRIC DRIVE—I would like to be advised how to proceed to show my employer in terms of dollars and cents the advantages which electric drives have over his present countershaft and belt drive installation. The efficiency of our 110 hp steam engine is low even at full load, and as the engine seldom operates at rated full load, the operating effeciency is very low. We are using some of the steam for heating purposes. Would it not be more economical to use a bleeder turbine rather than use an expansion valve? Is it possible to buy a bleeder turbine of 100 kw capacity? Would it be possible to use this bleeder condensing during the summer months. To what extent will the feasibility of the use of the bleeder condensing and non-condensing type be limited, economically? Is it possible to buy small size motors of low speed on the open market? The speed of our main shaft is about 200 r.p.m. How can I calculate the power lost in shaft and belt drives? M. W. D. (NEW YORK)

An approximation of the power losses in the shafting and belting may be made by running the machinery without load and determining the horse-power of the steam engine by means of indicator cards. There should be from 15 percent to 50 percent saving in changing from line shafting to electric motor direct drive. Having in mind the capacity at which the turbine would operate, the conditions suggest that an economical noncondensing turbine unit exhausting at a back pressure satisfactory for heating purposes, would be the best solution. We do not know of any bleeder turbines of this capacity. If one were obtainable, its condenser auxiliaries would consume an abnormally large percentage of the steam saved by condensing operation. The use of high-pressure live steam for heating purposes is always uneconomical. Desirable speeds for motors for machine tool applications are given in Mark's Mechanical Engineers' Handbook, page 1418. A motor of 200 r.p.m. would be seldom used, as it would be too expensive to build. Speeds between 900 and 1800 r.p.m. on the machines are generally required. Wood

working machines are essentially high speed, except in a very few cases. These motors are obtainable on the open market. L.H.

1950—Voltage Fluctuations Causing Direct-Current Motor Troubles—At the end of a 600 volt direct-current feeder we have a 100 hp compound wound motor driving some line shafting. An intermittent load at other points on this feeder causes severe voltage fluctuations, sometimes pulling it as low as 400 volts when suddenly the load will be cut off, causing a surge which results in flashing at the motor in question and tripping the circuit breaker, which is set at 50 percent overload. Aside from the installation of additional feeder or the application of low voltage release to the circuit breaker, is there any way of stopping the inrush of current to the motor? I have in mind the insertion of a choke coil and if you think this will prove successful will you please suggest a design. I.J.S. (NEW YORK)

The condition described is caused by the large amount of current that flows when the voltage rises. The motor is running at a speed which gives a counter e.m.f. corresponding to a 400 volt supply line. When increased to 600, the voltage causes a rush of current which the motor can not commutate. The normal current for a 100 hp, 600 volt motor is approximately 135 amperes. Assuming the line drop is ten percent or 60 volts, and applying Ohm's law, we have a line resistance of 0.45 ohms. Now, on a rise from 400 to 600 volts, the current which flows is due to the difference between line and counter volts. Assuming counter volts to be ninety percent of low line voltage or 360 volts, the current is $\frac{600-360}{0.45}$ or 535 amperes. This is four times full-load rating of the motor. On account of the high voltage and mechanical limits as to the number of commutator bars, the voltage per bar is high and it is relatively easy, compared to a lower voltage motor, to cause the motor to flash over under the conditions as outlined. The above calculations are given as an illustration, and are only approximate. On account of the time required for the motor to accelerate from the 400 volt speed to the 600 volt speed, a choke coil will lose its effectiveness before the counter e.m.f. has increased enough to hold the current back. To protect the motor under these conditions a resistor shunted by a contactor, a low voltage relay and an accelerating relay seem to offer the most satisfactory solution. The voltage relay should be adjusted to open when the voltage has dropped to that value below which it will cause flashing when it rises to normal. To be on the safe side, this should be considerably above the voltage that ordinarily will cause flashing. When this relay opens, it will open the contactor, cutting in the resistor. The resistor will lower the speed slightly. When voltage returns to normal, the voltage relay will close, bringing the accelerating relay into action. When the motor has accelerated to the proper point, the contactor will be closed by the accelerating relay, connecting the motor directly to the line. There may be cases where one step of resistance will not entirely eliminate flashing, but two or three steps may be required. This will be dependent on local conditions, and complete data as to voltage variation, line and armature resistance and other points will be required to determine this. The series coil may be differentially connected in which case it should be changed so as to add to the effect of the shunt coil. Increasing the number of series turns might improve conditions somewhat. A.L.H

1951—Synchronizing Two-Phase to Three-Phase Lines—Would it be possible to use the potential transformers connected as indicated in Fig. (a), and by grounding *e*, to synchronizing between *d* and *d'*, assuming positive polarity. The grounds of the potential transformers at *A* and *B* cannot be changed. What provision can be made so that a satisfactory synchronizing connection can be made between the high and low voltage sides? C.O.D. (NEW YORK.)

Assuming that power is supplied to the 2300 volt lines from some other source in addition to the 70 000 volt, three-phase, 2300 volt, two-phase bank of transformers shown, and that it is necessary to synchronize the two lines

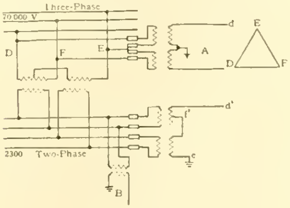
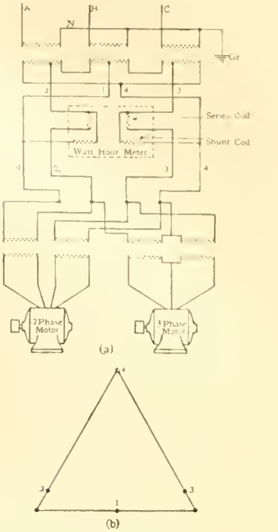


FIG. 1951 (a)

before connecting them together, synchronizing can be done between *d* and *d'* with the connections shown, if the transformers have the correct polarity. J.F.P.

1952—Metering Load on Secondary of Taylor Connection—In Fig. (a) both two and three-phase motors and lights are connected to the transformers. Will the two watthour meters register the correct amount of current used. I understand this is a special transformer and the connection is called the Taylor connection. Any other information regarding efficiency, etc., will be appreciated. J.P.V. (MINN.)

The meter and two-phase motor, as shown in the wiring diagram Fig. (a) are incorrectly connected. The Taylor connection is shown in Fig. (b). Two-phase power may be taken from points *1-4* and *2-3*; three-phase power from points *2-3-4*. To measure the power in the three-phase motor circuit the watthour meter shunt coil connected to points *1* and *2* should be connected to points *2* and *4*. The watthour meter will then be connected properly to measure the three-phase power. It is impossible to measure the two-phase and three-phase power with the one watthour meter. To measure the two-phase power one element of a polyphase meter should be connected to lines *1* and *4*; the other element of the meter should be connected in lines *2* and *3*. Refer to article in the JOURNAL for March 1919, on Three-Phase to Two-Phase Transformation for discussion of methods of transforming from three-phase to two-phase or vice versa.



FIGS. 1952 (a) and (b)

The total power can, of course, be measured on the primary side of the main transformers, by a three-phase meter and suitable instrument transformers. It would be better, however, to install two separate meters in the two circuits. A.R.R.

1953—Steel Conductors—In the construction of a 250 volt, 2500 ampere feeded line, I am considering the use of four 80 pound (to the yard) steel railroad rails, two rails for each polarity and spacing each set four feet apart. The entire distance of rail conductors to be 75 feet, and for the remainder of the distance or 150 feet, using four 1 000 000 circ. mil copper cables. My intention is to install the rails in a tunnel, the height of which is six feet, therefore allowing four feet spacing. I should be pleased to obtain data on the comparison of conductivity of steel and copper; also, allowable magnetizing distances for steel parallel conductors, and heat losses of relative spacing. D.F.Z. (KANSAS)

The parallel resistance of two 80 pound steel rails 75 feet long, is 0.00047 ohms. The parallel resistance of four 1 000 000 circ. mil copper cables, 150 feet long, is 0.000432 ohms. We are assuming here two steel rails in each side of the circuit and four cables in each side. The total drop for both sides of the circuit is then 4.5 volts at 2500 amperes, or 1.8 percent. The I^2R loss at 2500 amperes, is about 40 watts per foot for the two paralleled rails. Therefore, we should estimate that the rails would rise to a temperature of about 18 to 20 degrees C., while carrying 2500 amperes in the circuit, assuming still air. The comparative conduc-

tivity of the average steel used in rails compared to ordinary copper, is about 7.5 to 10 percent. By the "allowable magnetizing distances", we assume is meant permissible spacing from the standpoint of the stresses on the conductor. With 2500 amperes and a spacing of four feet as proposed, the pressure per foot on both rails on each side of the circuit will be 0.07 pound per foot, or 0.035 pounds per rail. These pressures vary inversely as the spacing between conductors and directly as the square of the current. Therefore, the stress under short-circuit conditions with any assumed value of current and spacing of conductors can be readily calculated. In general it may be stated as a rule that, when a direct-current supporting structure is strong enough to hold the heavy direct-circuit leads under normal conditions, it is heavy enough to prevent serious damage under short-circuit conditions. The heat losses of the conductors above are independent of the spacing, as long as this spacing is sufficient to permit ready dissipation of the heat. All of the above discussion assumes direct current, which we believe is intended in the present case. With alternating current, the heating would depend upon the frequency, material of conductor, form of cross-section, spacing, etc. Rails must be welded or well bonded.

R.C.S.

1954—STARTING SYNCHRONOUS MOTOR AS AN INDUCTION MOTOR—In starting up synchronous motors as induction motors, in some installations the open delta connection is used for starting, going over to closed delta at running as shown in Fig. (a). What are the advantages derived by using this connection? G.H. (CALIF.)

This arrangement makes it possible to connect the transformers permanently in delta for the running voltage and to start the motor from taps on the same

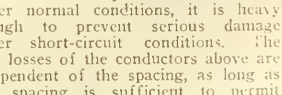


FIG. 1954 (a)

transformers. Also, it permits the use of a double-pole, double-throw switch, changing the connections of only two of the motor leads. J.B.G.

1955—SWITCHING LARGE TRANSFORMERS—Assuming that it is equally convenient to use either method, which way is best to cut out a 10 000 kv-a, three-phase, 110 000 to 6600 volt transformer that is connected to a large transmission network and is operating in parallel with other large three-phase transformers, a few of which have the neutral solidly grounded:—To open the low-tension switch first, and the high-tension switch last, or vice versa? In cutting in this transformer, which method is preferable, to close in the low-tension switch first or the high tension switch first? In cutting in large transformers, sometimes a very heavy charging current flows for a moment. If the transformer were closed in on the high-tension side first, would the choke coils shown in Fig. (a) appreciably reduce the magnitude of this rush of charging current? R.B.G. (MONT.)

In switching transformers that operate in parallel with other banks, the best procedure is as follows:—To remove a bank from service, first, disconnect the high-voltage side, then the low-voltage side. To put a bank into service, first

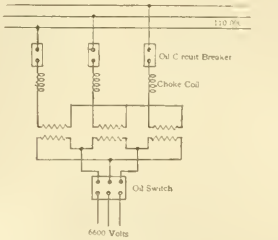


FIG. 1955 (a)

connect the low-voltage side, then the high-voltage side. If the choke coils referred to are large enough to reduce the switching surge appreciably, they will produce a considerable drop in voltage during normal operation.

H.F.P.

1956—NICHOLSON ARC SUPPRESSOR—What is the Nicholson arc suppressor, and how does it work? P.N.P. (KENTUCKY)

The Nicholson arc suppressor is for the purpose of suppressing arcs, such as are usually caused by lightning discharges on a transmission system. If the neutral of the system is grounded, or if it is large enough so as to have a heavy charging current to ground, an insulator which flashes over will cause an arc to form. The arc suppressor consists of three single-pole switches usually placed at the main generator station, and so arranged that whenever an arc occurs between one wire and ground, the switch on that phase wire will close for an instant and ground the wire, thus short-circuiting the arc so that it will be extinguished. This clears the system without the necessity of disconnecting the part of the circuit which is in trouble. The single-pole circuit breakers which form the suppressor arc usually actuated by a series coil in the main line, so that they operate whenever an excessive current flows. Sometimes they are actuated by potential relays which operate to close the switch on one wire when the potential on that wire falls to zero. In this case the relays and the switch mechanisms are usually interlocked so that only one-phase can be grounded at a time. The first installations of this device were operated by current coils, and were intended to clear short circuits between wires as well as between a single wire and ground. This method of protecting transmission systems has not been used to any great extent, probably because lightning disturbances frequently involve more than one-phase wire, thus resulting in short-circuits. This necessitates setting the protective relays very high, so as to allow the arc suppressor to operate before the relays will start to sectionalize the system. In case the short-circuit is of such a nature that the arc suppressor cannot clear the trouble, the resultant delay due to the slow action of the sectionalizing relays may cause all the load to be lost, before the trouble is cleared. Present practice indicates that best results are obtained by the use of a good system of automatic sectionalizing which will cut out defective sections of the network. Individual feeders can best be protected by means of the Ricketts service restoring scheme which trips out the circuit breaker and immediately recloses it. This momentary interruption to the circuit is sufficient to break any arc which may have been established and the service can easily be restored, without causing an interruption of more than one second. L.N.C.

1957—CONNECTIONS OF REACTIVE METER—Please give me a proper diagram of connections of a Westinghouse type S. I. reactive meter, including a diametric sketch of the arrangement of coils inside the meter, etc. What is the effect of reversing the current element? What is the effect of interchanging the voltage leads? O.A.L. (MARYLAND)

The diagram of connections for the Westinghouse type SI reactive factor meter is as shown in Fig. (a). The connections are for a three-phase reactive-factor or power-factor meter, these two meters being exactly the same except the scale calibration, which indicates the cosine of the phase angle in the case of the power-factor meter, and the sine of the angle in the case of the reactive-factor meter. The connections for the single-phase and two-phase meter are similar to the above, except that the coils which provide the rotating field are wound with an angle of 90 degrees between them instead of 120 degrees as above, and a reactance is inserted in series with one of these coils in the case of the single-phase meter to give the rotating field. Until a few years ago, the reactive meter was so designed that the rotating field was furnished by three current coils connected in star, and the moving vane was magnetized by a potential coil; whereas in the latest type meter, as indicated in Fig. (a), the potential coils furnish the rotating field, and a current coil magnetizes the moving vane. This, however, does not affect the discussion which follows. The effect of interchanging the current leads is to reverse the polarity of the field of the magnet-

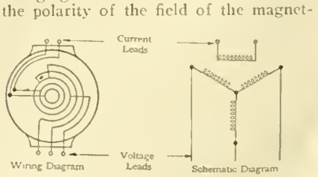


FIG. 1957 (a)

izing coil, and this will reverse the position of the pointer on the scale exactly 180 degrees. The effect of reversing any two of the voltage leads is to change the position of the pointer through approximately 110 mechanical degrees, in the case of a three-phase meter and hence to cause it to give an erroneous indication. Theoretically, the pointer should be offset through 120 mechanical degrees in the latter case. This variation, however, is caused by the fact that the current in the magnetizing coil has a slight lag, due to the fact that it is wound on an iron core. Hence, when calibrating, the moving coil is allowed to take its position for a given condition

of power-factor, and the pointer is then slipped ahead a few degrees on the shaft to compensate for this lagging current. Hence, when the direction of field rotation is changed, as when two of the voltage leads are exchanged, the effect is to introduce a variation in indication which is equal to twice the amount that the pointer was moved ahead when the meter was calibrated.

H.P.S.

1958—MERCURY ARC RECTIFIER—What can be done to a mercury arc rectifier rated at 220 volts, 60 cycles, alternating current, 110 volts, 30 amperes direct current, to reduce the charging rate to five amperes on a storage battery load and still maintain the arc in the mercury tube?

H.P.W. (INDIANA)

From the statement of the question it appears that the difficulty lies in the failure of the outfit to operate at low currents. This failure is due to the pulsations in the direct current, which bring the current at times below the value at which the arc is stable. This trouble can be corrected by increasing this low point, either by increasing the total current or by adding sufficient inductance in the direct-current circuit to reduce the amplitude of the pulsations. The simplest method is to add a shunt resistance which will increase the total current and thereby increase the minimum value. The addition of inductance in the direct-current circuit involves higher initial expense but results in more economical operation, in that the loss in the shunt resistance is eliminated. The choice between the two methods depends upon the operating conditions, such as cost of power, and the amount of service which is required. Without definite information as to the design and characteristics of the rectifier, we cannot advise what inductance should be used, but it is probable that a coil of 0.01 henrys would give satisfactory operation. There should be an air-gap in the magnetic circuit of this coil.

A.L.A.

1959—CONDUCTOR HAVING A HIGH NEGATIVE COEFFICIENT OF RESISTANCE—Can you tell me of any material which has a high negative coefficient of resistance? I would like to get some alloy which has at 70 degrees F., a very high resistance and at 200 degrees F. a very low resistance. I do not know of any such alloy and am afraid that there is nothing which will fulfill these requirements. However, I am wondering if there is not some kind of powder or paint which could be deposited on some insulating carrier, say a piece of pasteboard or fish paper, which would answer these requirements, that is, an exceptionally high resistance at 70 degrees F. and a comparatively low resistance at 200 degrees F.

L.A.F. (MASS.)

The class of electrical conductors to which you refer, having a large negative coefficient of resistance, is called pyro-electric conductors. Such materials are case silicon, boron, magnetite, sulphides and carbides. Most of them probably do not have a sufficiently large negative temperature coefficient to answer your purpose. Possibly, however, silver sulphide would fill your needs. Fitzgerald reports data on a sample having the following characteristics:—

Degrees C.	Degrees F.	Ohms.
20	68	1300
50	122	150
100	212	20
150	303	small

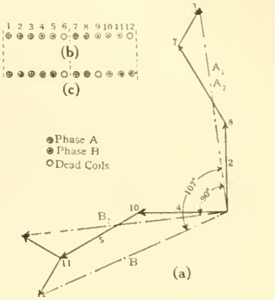
This material has a critical temperature above which the resistance is very small. This temperature depends upon the copper content. For pure silver sulphide the critical temperature is 170 degrees C. (338 degrees F.); with 0.5 percent copper, it is 163 degrees C. (325 degrees F.); and with 7.5 percent copper, it is 104 degrees C. (219 degrees F.). This conductor must be used with alternating current, as direct current reduces some of the sulphide to metallic silver and the material then becomes a good conductor at all temperatures. If it is possible to use sufficient current through the conductor to heat it appreciably, the effective critical point can be varied at will by varying the amount of the current. It is possible that you can obtain silver sulphide in usable form from the Fitzgerald Laboratories. Otherwise you had probably better make it yourself. We believe that Fitzgerald's 7.5 percent copper-silver-sulphide is made by heating an alloy of 92.5 percent silver and 7.5 percent copper in a bath of molten sulphur. The resulting sulphide is cast and then machined into a rod. If desired the sulphide may be rolled into strips, but this rolling must be done cold. If the material is worked hot, even at as low a temperature as 200 degrees C. the electrical characteristics are entirely changed. The sulphide will then have a temperature coefficient of approximately zero instead of a large negative value. According to the Bureau of Standards, silver sulphide may be made by melting the chemically prepared powder in a porcelain crucible, tightly covered to prevent oxidation. The melting point is approximately 825 degrees C. For further details see the *Transactions of the American Electrochemical Society* for 1914, p. 303; also *Bureau of Standards Bulletin*, Vol. 14, p. 331.

T.S.

1960—RECONNECTING THREE-PHASE, 2200 VOLT ALTERNATOR TO TWO-PHASE, 2200 VOLTS—The writer had occasion to reconnect a three-phase alternator, connected twelve pole series delta to two-phase series. The three-phase voltage originally was 2200 volts and it was desired to reconnect for 2200 volts, two-phase. The voltage working out rather high, it was decided to cut out 12 of a total of 72 coils. These coils were equally divided throughout the machinue, which cut out every sixth coil of the stator winding. The balance of the coils were then connected in groups of 3-2, 2-3, etc., and the long group connection was used, namely, going once around the machine and taking in all the North pole groups, then coming back and taking in all the South pole groups of each phase. This alternator so connected was put on a motor load entirely, two-phase, 4 wire, and it was found that the phases were considerably unbalanced at full load, the current read on one-phase being 30 amperes and on the other phase 51 amperes. It was first believed that the grouping was done incorrectly, but on checking it was found to be correct. It was, therefore, decided to put in all the coils throughout the machine, bringing down the saturation considerably, with the result that the phases balanced correctly. The writer would like to know why the phases were unbalanced with the grouping and coils cut out.

G.P.E. (NEW JERSEY)

Your idea of cutting out certain coils to increase the saturation is all right. However, the dead coils of your diagram in Fig. (b) are not symmetrically placed with respect to the two phases and the resultant angle between the voltages of the two phases is displaced from 90 degrees. In this particular case the angle is 107 degrees which means a relative displacement of 17 degrees. As you have indicated, the currents of the two phases are unbalanced and the power outputs are different. Fig. (b) represents the connections as they were



FIGS. 1960 (a), (b) and (c)

with a dead coil every sixth slot. The two phases are distributed over only five slots and are thus crowded together. The voltage diagram shown in Fig. (a) shows the vectorial relations of the voltages of the various slots, the resultant voltages of the two phases are A_1 and B_1. Fig. (c) is a proposed balanced condition. The dead coils are unevenly spaced with reference to the slots—that is they lie in slots *6, 9, 18, 21, 30*, etc. The coils of the two phases are distributed the proper distance apart and the voltages of the two phases correspond to A_2 and B_2 of Fig. (a).

E.B.S.

1961—GROUNDED TRANSMISSION LINES—A transmission line of 81 kilometers has a pressure of 88 000 volts, the transformers are connected delta-delta, and the alternator is connected star with the neutral point grounded. The voltage is stepped up from 6000 to 80 000 giving a ratio of 14.6. If one of the transmission lines becomes grounded, what will the voltage on the other wires be; also what effect will this have on the low-voltage side of the transformer? Will the low voltage be increased considerably? By connecting only one wire of the above transmission line, that is, energizing only one wire and leaving the other two open at the station, we obtain a true signal for ground in the section where this line is connected. There are 600 insulators of 2000 megohms each in each line and the wires which were left open had only about 20 station insulators for each line. What would the voltage from the energized wire to ground be in this case?

J.A.V. (BRAZIL)

The fact that the generator neutral is grounded has practically no effect on the high-voltage side of the transformers, and the transmission line is operating with a free neutral. If the line capacities are balanced, the voltage of each line to ground will be 46 000 volts and the charging currents in the three wires will be equal. When one line is grounded, the voltage of the other two lines to ground will be 80 000 volts. The charging current in these two conductors will be increased about 30 percent each and in the grounded conductor it will be approximately double normal. Now if only one conductor is connected, it will tend to come to a lower potential to ground than normal, the amount of change being dependent upon the relative capacity of this line and that of the remainder of the system still connected. If there is little capacity in the remainder of the system the conductor will approach ground potential and the terminals of the other conductors will approach 80 000 volts to ground, which is the condition holding in the case of a grounded conductor. The grounding of one of the lines on the high-voltage side of the transformer will not effect the lines on the low-voltage side as they are two distinct and separate circuits, well insulated from each other. The true signal for ground is due to the condenser effect of the charged line, which depends upon the relative capacity of this line and that of the remainder of the system still connected.

A.W.C.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

JANUARY 1921

Types of Transition Used to Obtain Series-Parallel Operation

In the early forms of railway control, straight rheostatic notching was employed to obtain acceleration. The motors were connected permanently in parallel, and the resistance was cut out notch-by-notch, until the trolley voltage was applied directly to the motors. Although this method of operation gives the simplest form of connection with the simplest design of controller, it had one inherently bad characteristic. As all the motors are in parallel, the starting current is the sum of the currents in all the motors. The resistance must have sufficient capacity to carry this current throughout the acceleration, requiring a resistor of heavy design, and producing high resistance losses. Hence it was deemed advisable to use a system where the motors would be connected first in series and then in parallel, in order to reduce the current on starting.

With the series-parallel system of control, the transition point is the point of change from the series connection to the parallel connection of the motors.

TYPES OF TRANSITION

Three general types of transition have been employed in railway control apparatus, as follows:—

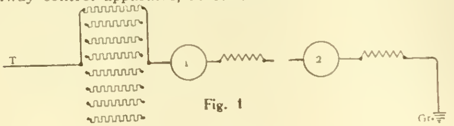


Fig. 1

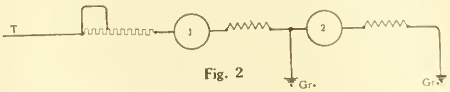


Fig. 2

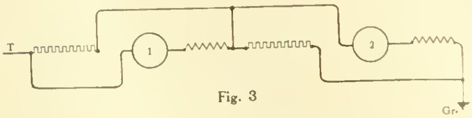


Fig. 3

FIG. 1—OPEN CIRCUIT TRANSITION

FIG. 2—SHUNTING TRANSITION

FIG. 3—BRIDGING TRANSITION

Open Circuit Transition—The first series-parallel control employed the so-called open circuit transition. With this connection, when going from series to parallel through transition, the motors were disconnected from the line. As the power to the motors is interrupted, the car tends to lose momentum at this instant. When power is again applied to the motors in the parallel connection, the torque is renewed suddenly, causing jerky action of the cars. This form of transition has two inherently bad characteristics:—

1 Heavy currents are broken during transition.

2 The motors lose torque at this point. This is particularly bad when climbing grades.

Connections during transition are shown in Fig. 1.

Shunt Transition—To eliminate the undesirable features of the open circuit transition, a scheme of connections was devised, whose name is taken from the shunting connection employed. One of the motors in a two-motor equipment or two of the motors in a four-motor equipment are short-circuited in transition. In this case, there is no open circuit, but there is a loss of torque on the motor or motors shunted out.

So far as the question of torque is concerned, this method of transition is better than the open circuit transition, as half of the motors are delivering torque to drive the car wheels. There being no open circuit during transition, one of the most objectionable features found with the open circuit transition where heavy currents are opened is eliminated. The method of connections for this type of transition is shown in Fig. 2.

Bridging Transition—To overcome the loss of torque obtained in both the open circuit and shunt transitions, and to obtain a greater number of notches for locomotives and automatic equipments, the bridging method of transition was evolved. With this connection, there is no loss of torque whatever during transition, as both motors are connected across the line at the same time; in fact, an increase in torque can easily be obtained during this period. To prevent a short-circuit during the transition period, each motor or pair of motors is paralleled with a section of the starting resistance. The connection between the two motor circuits is made with a switch or finger and contact through which the current may flow in either direction, depending upon the speed at which the car is running, and the value of the resistance used to parallel the motors. Connections during transition for this scheme are shown in Fig. 3.

APPLICATION OF THE DIFFERENT METHODS OF TRANSITION

1—Open Circuit—This scheme of connection is only being used on some of the older types of platform controllers, having been superseded by the shunting or bridging schemes. It was limited in its application by the arcs formed during transition.

2—Shunting—Practically all light traction equipments using hand control, whether of the platform or remote type, employ this method of connections for changing from series to parallel. Some of the smaller types of locomotives or baggage car equipments, used in locomotive service, also use this connection. When cutting out motors of a four motor equipment, using shunt transition, it is advisable to see that the motors of a pair of motors cut out are mounted on separate trucks. This is to make sure that torque will be applied to each truck during the transition period.

3—Bridging—The majority of automatic equipments in light traction service, and also locomotives, use the bridging method of transition. On automatic equipments, the operating characteristics of the bridging switch as affecting the control circuits are essential. With the standard hand control type where shunting transition with remote control switches is used, it is necessary to furnish an extra piece of apparatus, in order to obtain automatic control. With the bridging method of transition, it is unnecessary to pay any attention to the method of connecting the motors, as to whether each pair of motors uses one motor from each truck or not.

H. R. MEYER.

THE ELECTRIC JOURNAL

VOL. XVIII FEBRUARY, 1921 No. 2

Regulation by Synchronous Converters

The booster-type synchronous converter has now held undisputed possession of the direct-current lighting field for ten years. From 1908 to 1910 or 1911, the split-pole converter was an active contender, especially in 25 cycle systems, but with the introduction of commutating poles, about 1911 and the rapid extension of 60 cycle systems since that time, serious rivalry has disappeared. Recently there has arisen considerable discussion among central station engineers as to whether the high performance standards and flexibility of the booster converter are justified in all converter applications, and it has been proposed to economize on the first cost by using a simple converter and obtaining a smaller voltage range by reactance and shunt field current control.

There is, of course, nothing new in the use of reactance and variable excitation for obtaining voltage range. It is one of the oldest methods in point of use, if not of conception. In this connection, it is interesting to note that, while Chas. F. Scott patented the fundamental idea of the booster converter in 1893, it was not until 1907—thirteen years later—that the first application to Edison service was made. Messrs. B. G. Lamme and R. D. Mershon (then an engineer with the Westinghouse Company) developed the principle of reactance control in 1896 and it was immediately applied in railway service. So there is no new problem for the designer, the manufacturer or the operator. It is simply a problem of application, to analyze the characteristics of the converter operating under variable power-factor, to determine permissible values of lagging kv-a that can be supplied by the transmission system and to determine the necessary range in voltage in the direct-current system. Briefly, the simple converter, with reactance control, is at its best in locations and on systems where the drop in alternating voltage is negligible, where the desired range in direct-current voltage is small—say within 5 percent above and below normal converter voltage—and where the transmission system can supply lagging kv-a equal approximately to half the converter kw rating, without objectionable results. Conversely, the good qualities of the booster converter show to best advantage when the drop in alternating voltage is considerable, when a wide range in direct-current voltage is necessary and when operation at 100 percent power-factor is important.

Mr. Hague's article, in this issue of the JOURNAL, presents an analysis of the characteristics of the simple converter with reactance voltage control that should be of great interest and value, particularly to engineers responsible for the operation of converter substations. The discussion of reactance control has directed attention to the varying practice of power companies in measuring the converter power-factor. Until a few years ago, it was common practice to operate shunt-wound converters at 100 percent power-factor, connecting the current and voltage windings of the power-factor meter on the low tension side of the converter transformers. This practice favored the converter. With the growing appreciation of the advantages of high power-factor on the line, converters began to be purchased and operated on the basis of 100 percent power-factor on the line side of the converter transformers. Also with the increasing size of units, it became more and more difficult to connect the current windings of the power-factor meter on the low tension side and measurement on the high tension side became more convenient. Some operating engineers have compromised, in the interest of convenience, on current measurements on the high side and voltage measurements on the low side. This seemingly unimportant detail becomes a matter of considerable consequence when comparisons are made between the case of a simple converter having high reactance transformers for voltage control and a booster converter with low reactance transformers. F. D. NEWBURY

Railway Utilities Approaching Stability

Generally speaking, no industry can continue to exist if its revenue does not equal or exceed its necessary expenditures. That many of the utilities have been attempting an impossible feat is only too well known to those who have been in touch with their problems. A year or more ago the future looked almost hopeless. During 1920, however, there came a decided improvement both in the actual conditions of operation and in the attitude of the public and of the regulatory bodies. Mr. P. H. Gadsden, President of the American Electric Railway Association, in reporting on the electric railway industry for 1920, exhibits a decidedly hopeful attitude, indicating that the reports received show a gradual approach to a stable basis in that industry.

At the same time he presents a word of caution. Many companies, during the past few years, have strained their financial resources to the limit by merely keeping their cars running, and have not been able to consider proper maintenance of their properties. Mr. Gadsden's plea, therefore, is that, assuming that rates have been or soon will be adjusted to a position which will enable the properties to avoid receiverships, an early reduction of such rates should neither be expected nor advised until the operating companies get their properties into first-class condition.

While it will doubtless take time for some railways to eliminate annual deficits there should thereafter begin a period of rehabilitation by which permanently improved and well-equipped transportation service can be supplied to the American public. A. H. MCINTIRE

The Dual Drive Units

IVAN STEWART FORDE
Manager, Small Turbine Division,
Westinghouse Electric & Mfg. Company

ECONOMY is the watchword of all the forces that have to do with the operation of a power house, regardless of whether this generating station be the workshop of a large public utility or the means of providing some industrial plant with electrical energy. Economy is the question that is being studied as never before by the operating, engineering and managerial elements of any business requiring the need of electrically generated power.

On one hand, we hear of boilers being planned for 500 pounds steam pressure, in order to effect an economy in the prime mover; we know of refinements continually being made in the prime mover itself tending towards a more economical utilization of the heat in the steam, and of scientifically operated boiler rooms. On the other hand, it is not generally known that economies can also be effected in first and operating costs by the proper selection of auxiliaries. Suppose, for instance, a dual or double economy could be obtained, one that would be of importance to the manager in first cost, and to the operator in plant economy; could either factor in central station operation ignore it?

A notable advance has been made in auxiliary economies of late, especially in large central stations, by resorting to what is known as a house turbine, in order to reduce the number of steam auxiliaries in plants where the exhaust steam demand is cared for in another form. This house turbine is, in effect, a turbine-generator unit large enough to supply electric motive power for motor driven auxiliary apparatus for condensers, boiler feed, service and sump pumps, stoker fans, etc. In such installations, the variable exhaust steam demand, if any, is taken care of by the house turbine, which is designed to operate either as a non-condensing unit or under relatively low vacuum.

But even with the installation of a house turbine, there are certain auxiliaries for which it is desirable to have a duplication of the electric drive if all possible failures are to be prevented. The number of auxiliaries about a large power house that require some form of drive presents quite a formidable problem to the operator. Some of the more important auxiliaries are:—

Stokers
Stoker draft fans
Boiler feed pumps
Condenser pumps
  a—circulating
  b—air pump
  c—condensate
Service pumps
Exciters

An operator, therefore, has the big problem of keeping the auxiliaries operating continuously, in spite of the possible failure of either the steam or electric drive, without a sacrifice in plant economy in doing so. And since continuity of service of auxiliaries is one of the main factors in keeping the main units in operation, it is on them that we shall dwell in this article, with the suggestion that a sufficient number of them be equipped with a double or dual drive.

With dual drive, the auxiliaries so equipped would have a motor on one end and a turbine on the other, thus giving positive assurance that as long as there is steam in the boilers and the driven auxiliaries are in working order, it will be possible to operate the boilers, stokers, condenser and exciters at all times. Where it is undesirable to have both the turbine and motor combination on a particular piece of apparatus, a duplication of the auxiliary, with a turbine in one case and a motor in the other, is the proper solution.

As an illustration, in the case of three boiler feed pumps, and particularly where there is a house turbine

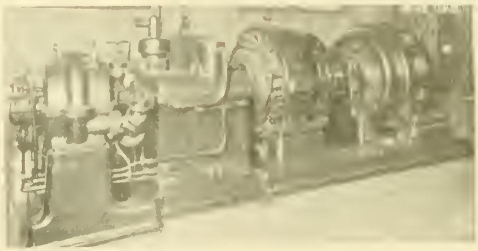


FIG. 1—300 KW DUAL DRIVE EXCITER UNIT
During the past two years this unit has been operating in conjunction with a 200 kw standard geared turbine unit, at the Cleveland Municipal Electric Light Plant, Cleveland, Ohio.

installed furnishing the exhaust steam, one of these pumps at least should be driven by a steam turbine. And this same argument would hold good for stoker fans. On the condenser pumps in large stations, particularly with twin jet condensers, the dual drive of one unit by both a motor and steam turbine is a practical installation. With large surface condensers, where the circulating, air and condensate pumps are separately driven, the problem becomes somewhat difficult, and the local conditions of space and pumping arrangements must be considered.

In the case of the exciter, instead of having a separate motor driven exciter unit and a separate steam turbine exciter unit, the two exciters should be consolidated into a single excitation unit of the dual drive type. Such a unit would then consist of a steam turbine, direct-current generator and alternating current motor. The first cost would naturally be less than the corresponding cost of a motor generator set and a steam tur-

bine driven exciter unit, and hence an initial or first cost economy is secured.

From an operating or plant economy standpoint, the dual drive unit leaves nothing to be desired. It is a perfect unit with respect to the driving elements. The turbine, the direct-current generator and alternating-current motor are all mounted upon a cast iron bedplate. The steam turbine and electric motor being

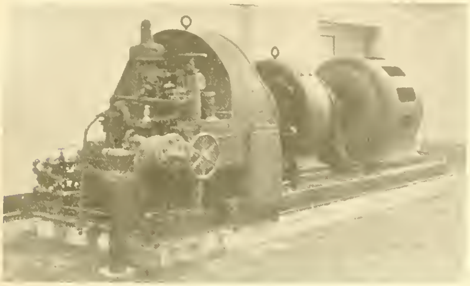


FIG. 2—350 KW DUAL DRIVE EXCITER UNIT

One of the three units to be installed in one of the Duquesne Light Company's stations in the Pittsburgh district.

connected at their respective ends to the generator by means of couplings, it is very easy to remove one or the other. In some of the earlier installations, the usual motor generator set was embodied in this combination, with the turbine coupled to the motor end. The idea was that it afforded easier access to the generator commutator, but in later installations this has been modified so that the generator is the middle element of the unit, thus making it possible and practicable to disconnect either the turbine or the motor. This advantage, in our opinion, is sufficient to outweigh the problem of getting at the commutator.

In ordinary operation, the unit consisting of a turbine, a generator and a motor is in reality a motor generator set, with the steam turbine acting as the "insurance policy" for continuity of operation. In a case of this kind, the turbine is idling (being furnished with just sufficient steam to prevent excessive friction heating), with its governor so set that should the electric motor show any disposition to lower its speed, the governor on the turbine instantly admits steam to the inlet valve, and the load is then carried by the turbine. This type of unit is so arranged that either the steam turbine or the motor will individually or collectively develop the maximum capacity of the exciter.

It might be proper to answer certain pertinent questions:—

1—In the event of an accident to the electric motor, will the turbine quickly take up the load? The turbine will instantly pick up the load and carry any part or all of it.

2—Under similar circumstances, will the motor carry the load in the event of an accident to the turbine? It will.

3—Can this combination be so arranged that the turbine will carry variable loads at the dictation of the operator; say 20 percent at one time, 40 percent at another and 60 percent at other times, the motor pulling the balance? It can.

4—Can the load be shifted easily from one driving element to the other without disturbing the regulation of the excitation current? Yes.

5—Can the steam turbine exhaust steam be used for heating incoming feed water? Aside from the guarantee of continuity of excitation, the question of exhaust steam demands as applied to the dual drive unit is its big operating feature. The idea is to pass only sufficient steam through the turbine to supply the necessary exhaust steam heat to the incoming feed water, so that no steam is lost by exhausting it to the atmosphere, the remaining load being carried by the motor.

The possible causes for failure of the motor to function may be classified as follows:

a—Sudden voltage drop due to line trouble would tend to lessen its speed.

b—Frequency of the main unit furnishing power to the motor may drop due to overloads or low steam pressure, causing the motor to slow down

c—Possible burn out of motor.

It is during such periods as these that the steam turbine not only acts as a "capacity puller" but a direct-current voltage regulator as well. It will therefore be seen that such a unit is very elastic when viewed from an operation standpoint.

The question of the economy of such a unit with reference to power house economy may rightfully come up at this time. No power house wants to waste a single pound of steam by exhausting it to the atmosphere. The ideal way is to utilize all exhaust steam. A central station should produce sufficient exhaust steam to create a heat balance only. That is, any well conducted power house will have only enough continually operated steam auxiliaries to produce the requisite amount of exhaust steam to heat the incoming feed water up to the ideal temperature, leaving aside, of course, the fact that many engineers have a natural perference for keeping their auxiliaries independent of the generating units, figuring that as long as they have steam in their boilers they will, at least, be assured of

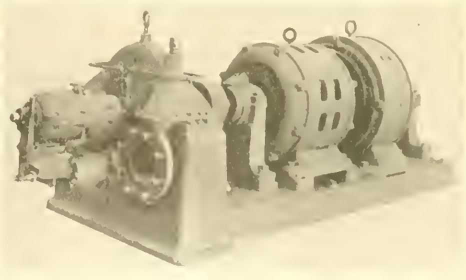


FIG. 3—50 KW DUAL DRIVE EXCITER UNIT FOR THE MERIDEN ELECTRIC LIGHT COMPANY, MERIDEN, CONN.

Load on this turbine can be varied to meet the exhaust steam demand while the unit is in operation.

auxiliary power. But the cost of fuel has even compelled many operators who favor this scheme to reduce it to a minimum, particularly where there is a surplus of exhaust steam.

In the case of the dual drive unit, either on pumps, fans or exciters, the steam consumption can be adjusted so that it is unnecessary to generate more steam than

is needed in the system. This is accomplished by making the electric motor carry the major portion of the load and the steam turbine the remainder up to the point of taking care of the heat balance or exhaust steam demand, it being possible to vary the load on the turbine from zero to maximum while the unit is in operation without in any way interfering with the operation of the motor other than reducing the motor load.

With the steam turbine large enough to handle the maximum load requirement, and its governing mechanism so set as to vary the capacity it should develop, depending on the demand for heat, it will be seen that the question of its steam consumption rate does not interfere in any way with the endeavors of the operators to maintain a perfect heat balance.

The question of unit economy with respect to plant economy has been worked out by arranging the dual drive units with either direct connected or geared turbines for the steam drive. The direct-current generator must, of necessity, be of relatively low speed. That means that the steam turbine driving it, if direct connected, must also be of the same speed. Slow speeds however, tend to lower the efficiency of the turbine, with the result that from a unit standpoint, the efficiency of the direct-connected set would not be as good as though a moderately high-speed turbine and gear were used for driving the generator.

Direct-connected units are installed where the purchaser has a preference for this type; where the steam turbine will only be used as a stand-by, or for variable or moderate amounts of steam. Some central stations, however, prefer a dual drive unit with geared turbine drive that might never in normal circumstances furnish more than a minimum amount of exhaust steam for heating purposes, because they feel that there might be times when the entire load would have to be carried by the turbine. In this case, the question of unit steam consumption becomes of paramount importance. This combination would obviously be more econmical than the direct-connected set and would, if operated only for a short period, more than justify the additional cost of the reduction gear.

The two combinations of dual drive unit will always have their respective fields and partisans, and the particular installation of one or the other will be governed by the exhaust steam requirements, available space, the likelihood of continuous turbine operation, first cost and the preference of the operator for one or the other. The majority of small and medium capacity dual drive units have up to this time been of the direct-connected type, but in capacities of 300 kilowatts and larger the geared unit is undoubtedly the better and more economical installation, particularly where the steam turbine will always be operated under load. Where no steam is required from the turbine in these large sizes, space and first cost will enter into the selection.

So far as the electric motor is concerned, there is also the choice of two methods of drive, namely, an induction motor or a synchronous motor. The operating preference is for the induction type because it is somewhat simpler than the synchronous type, which requires the complication of direct-current excitation. Moreover, the synchronous motor will have a greater tendency to pull out if there is a drop in voltage. The induction motor will drop in speed under such conditions and ease off its load, while the synchronous motor will maintain the same speed and hold on to its load, so that even with the same pull out torque the induction motor has better operating characteristics for a dual drive unit, with the steam turbine arranged for load carrying with any slowing down in the induction motor, to say nothing of the advantage of eliminating the necessary excitation on the synchronous type.

Units of the dual drive type are not passing through the experimental stage, for they have been in successful commercial power house operation for several years. The capacities of these combinations

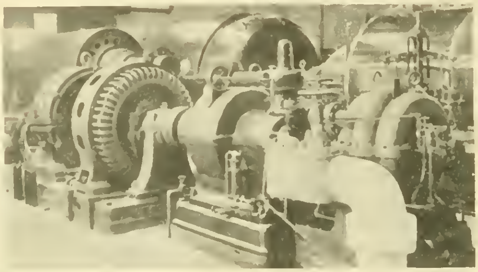


FIG. 4—200 KW GEARED DUAL DRIVE UNIT OPERATING IN THE PLANT OF THE NARRAGANSETTE ELECTRIC LIGHT COMPANY

This unit is equipped with a special device, on the steam end, for varying the load on the steam turbine.

vary from 15 up to 500 kilowatts. A 500 kilowatt unit, the largest size yet contracted for to our knowledge, will be installed in the plant of the Narragansett Electric Lighting Company, Providence, R. I. It will be of the geared type and will be a companion unit to a 200 Kilowatt geared dual drive unit now installed in the same station. The 200 kilowatt unit has been operated in parallel with a 300 Kilowatt geared steam turbine exciter set previously installed. It is interesting to note however that three 350 kw dual drive direct-connected units will be installed in one of the power stations of the Duquesne Light Company, of Pittsburgh.

An interesting feature in connection with this line of dual drive units is that the steam turbines are designed primarily for installation in central stations having high steam pressures and high superheat, resulting in extremely high total temperatures. The steam turbines are provided with center line supports which permit expansion of the cylinder without causing alignment difficulties.

Commutator Brushes for Synchronous Converters

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THE selection of suitable brushes for commutator use involves both electrical and mechanical considerations, depending upon the characteristics of the machine in question. From the electrical standpoint, any brush, to be suitable, must have proper contact drop to keep the short-circuit currents under the brush well within control with a minimum brush I^2R loss, when the machine is operating under normal conditions; and, in addition to this, must also have sufficient current carrying qualities to prevent overheating. From the mechanical standpoint, the peripheral speed of the commutator, angle of the brushholder, and whether commutator mica is undercut or not, are all important factors to consider in the selection of a brush with proper characteristics to give long brush life with low friction losses and, at the same time, ride smoothly on the commutator so as to give the minimum amount of noise and vibration. These electrical and mechanical characteristics must all be given consideration in the selection of brushes for any given machine, if best commutation and all around satisfactory operation is to be obtained with a minimum amount of maintenance and upkeep expense.

The service required of a machine is another important factor in deciding the proper grade of brush to select. For instance, railway service with a load factor of 65 percent during 12 daylight hours and 20 percent during 12 hours night service, will obviously permit greater latitude in brush application for a given machine, than where the same machine is applied to electrolytic service with a 98 percent load factor over the entire 24 hours of the day.

While it must be understood that every application of brushes for commutator use should be decided only after consideration of all the merits and characteristics involved in each individual case, the following tabulation will be found useful as a reference in approximating most of the average cases:—

Carbon Graphite Brushes are suitable for use on non-undercut commutators, with commutator speeds up to 3000 feet per minute, and brush densities not exceeding 35 amperes per square inch. This grade of material includes all brushes commonly called carbon brushes. They are composed chiefly of amorphous carbon or coke with only enough graphite added to give the brushes slight lubricating qualities.

Graphitized Carbon Brushes are adapted for use on undercut commutators with commutator speeds up to 4500 feet per minute, and brush densities not exceeding 50 amperes per square inch. On apparatus in railway service, with the usual load factors, this grade of brush is applicable on commutator speeds up to 5500 feet per minute and densities of 55 amperes per square inch. This grade of material includes brushes which contain considerable graphite in their composition with the balance of amorphous carbon or coke. This class of material usually has a final baking operation carried to a high temperature, which results in modification of the material, leaving most of it in the form of graphite.

Graphite Brushes are good for use only on undercut commutators with commutator speeds up to 6000 feet per minute, and brush densities for all classes of service at heavy load factors and densities of 60 and 65 amperes per square inch. This grade of material is composed almost entirely of graphite except for a little copper in some cases, and the binding material necessary to hold the particles of graphite together.

Generally speaking, the hard or carbon brushes have abrasive or scouring action on commutators, while the softer graphite grades lubricate and give the commutator a good polish. It has been found, however, that graphite brushes often cause bad grooving of the commutator, and when replaced by a harder brush of the graphitized carbon grade this grooving would practically disappear. This has been found to be the case more particularly on older machines where the direct-current brushes were staggered alternately, and the most feasible explanation seems to be that a minute arcing action takes place under the face of the positive (current leaving commutator and flowing into brushes) brushes, which burns away the copper and causes it to be carried across from the commutator to the brush. Small particles of copper imbedded in the face of the brushes will often be found as evidence of this action if examination of the brushes is made.

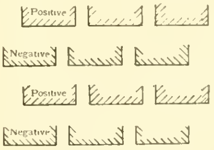


FIG. 1—INCORRECT METHOD OF STAGGERING BRUSHES

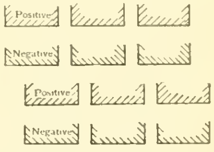


FIG. 2—CORRECT METHOD OF STAGGERING BRUSHES

The incorrect method of staggering brushes is shown in Fig. 1. It will be seen from this sketch that any action peculiar to either polarity is cumulative when all brushes of each polarity are in the same path entirely around the commutator.

The correct method of stagger is shown in Fig. 2. With this arrangement, any action tending to take place under brushes of one polarity will be neutralized, in a way, by the brushes of opposite polarity being directly in line with them. This arrangement gives a more uniform wear over the entire face of the commutator, and thus permits the satisfactory operation of certain grades of brushes where grooving trouble may have been experienced with the incorrect scheme of staggering.

As the progress in design of commutating machines during the past few years has tended steadily toward higher speeds, superior composition in brushes has been required, and the maintenance cost of the apparatus has obviously come to be an item of more consequence than was the case with the older, slower speed, heavier (lbs. per kw) machines. It has occasionally been found that although sparkless commutation has been obtained by the use of some particular high-grade graphite brush, objection has been raised to excessive maintenance costs involved, due to the cost of the brushes themselves, and the frequent renewals required, unless the commutator was kept in exceptionally good condition. In several cases of this kind substitution of a harder graphitized carbon brush has been made and exceptionally satisfactory results obtained. Although usually a change of this kind is accompanied by some slight pin sparking, many operators feel that a compromise involving only a slight sacrifice in the commutating performance of their apparatus is warranted when maintenance costs can be so materially reduced.

In cases where serious commutation trouble is being experienced, an inspection of the apparatus is always desirable in order that a thorough analysis of all conditions pertaining to the operation and service may be made. In cases where trouble is inherent with the brushes alone, and recommendation for a change in grade seems to be necessary, the brush manufacturers retain a staff of capable representatives whose services are always available upon request in all matters pertaining to brush applications.

Voltage Regulating Systems of Synchronous Converters

F. T. HAGUE

THE INTRODUCTION of the synchronous converter as a source of power supply for railway and industrial loads early developed the necessity of some form of voltage control of wider range than that which is inherent in the converter itself. In the early 90's the power supply units were of small capacity, as also were the industrial loads, permitting a concentration of power consumption close to the source of power supply. The railway systems naturally required the distribution of power over long distances but, fortunately from one point of view, the difficulties incident to keeping railway systems running at all were, by comparison, of such magnitude that voltage regulation of the power source was a matter of relatively small importance.

Steadily continued growth of industrial loads, both in the power consumption per unit and the distribution over a greater area, was accompanied by the development of larger power supply units and larger central stations. Combined with this tendency, the rapid development in reliability of operation of railway systems forced an early consideration of the problems of power distribution and voltage regulation when synchronous converters were used. Economy of operation and reliability of service favored the development of large distributing stations, and this development further served to accentuate the inherent defects of absence of voltage control of synchronous converters in service where some voltage control was required.

Chas. F. Scott, in 1893, proposed the first form of the now well known booster-type converter, (Pat. 515885), consisting of a simple converter connected in series on its alternating-current side with a small alternating-current booster mounted on the converter shaft. His object was limited to the maintenance of constant direct-current potential or compounding proportional with the direct-current load and was accomplished by connecting the field winding of the alternating-current booster in series with the converter direct-current load circuit. Although among the first to be conceived, this type of machine lay dormant until the electrical industry developed to a point where its revival, with slight modification, became a necessity for the proper and efficient control of voltage of converters supplying industrial networks.

Three years later, in 1896, the fundamental principle that an out-of-phase, or wattless current flowing through a reactance would induce an in-phase voltage was commercially introduced into synchronous converter distribution systems by R. D. Mershon and B. G. Lamme. (Pats. 571836 and 571863) Their systems differed only in detail, Mr. Lamme using the inherent reactance in the alternating-current distribution circuits while Mr. Mershon covered the insertion of separate external reactance. While the initial object was to provide automatic regulation, whereby the voltage delivered to the direct-current circuit would be automatically adjusted in accordance with the changes in direct-current load, it was later enlarged by Mershon (Pat. 620343) to provide means whereby the voltage delivered to the direct-current circuit might be adjusted in accordance with the requirements of the load. From patent interferences, it also developed that Dr. C. P. Steinmetz had independently proposed somewhat similar arrangements. This appears to have been the inception of a system of electrical distribution still used on most railway converters, comprising an alternating-current supply containing reactance and a synchronous

converter provided with means for varying the ampere-turns of its shunt or compound fields in order to vary the voltage at the direct-current terminals. It is interesting to note that the disproportionate increase of armature coil heating caused by wattless currents was not taken into account until some time after this system was conceived.

While the reactance controlled converter was immediately destined to take a leading part in railway power supply, there were certain conditions which prevented it from fulfilling all of the requirements of industrial and lighting service. The railway units operated over a desirable range of power-factor, from lagging at light load to leading at overloads and the increased armature coil heating and average efficiency over the ragged load cycle met in railway work, were reasonable and satisfactory. The liberal thermal capacity of the low-speed converters of this period made them relatively unaffected by the increased armature heating caused by wattless currents when operating on a typical railway load cycle consisting of intermittent peak loads. The industrial units were ordinarily of much larger size and in many cases required a wider range of voltage than the railway units. The load cycle was, moreover, much more nearly constant, and there was no generally desirable relationship between the converter power-factor and the amount of load, so that armature heating due to wattless currents became a serious problem and the total efficiency was not all that could be desired. About 1897 the British Thompson-Houston Company brought out a wide range reactance controlled converter, wherein wide range was obtained by means of high external reactance and correspondingly small wattless current in the converter armature. Other operating characteristics, such as low power-factor of converter and transformer as a unit, poor stability and efficiency, combined to prevent this type unit from persisting.

For industrial work, the variable voltage transformer, typified by the induction regulator, came into vogue in 1897 and continued until about 1904. It embodied many desirable characteristics, chief among them being wide voltage range, good efficiency and the use of a standard type converter free from the additional heating of wattless currents. Its defects arose chiefly from the cost of the regulator when built for large size units, and the introduction of an additional piece of apparatus taking up valuable floor space. A large number of non-commutating pole converters for use with induction regulators have been built and are still being operated successfully, although in many of the larger systems they are being replaced by larger capacity, higher speed booster converter units of more modern design which occupy the same floor space.

Until 1899 all voltage control systems for synchronous converters functioned by employing external means to control the magnitude of the alternating-current voltage impressed on the converter rings, either by voltage generated in an external booster or voltage induced in a reactance coil by out-of-phase currents. At this time a new type of converter was proposed by Mr. Woodbridge, (Pat. 679812) afterwards termed the "split-pole" converter, in which the direct-current voltage could be regulated with the alternating-current supply voltage held constant. This was accomplished by splitting the main pole pieces into three sections, each section being controlled by an independent field coil wound around it, thereby allowing any desired distribution of the lines of magnetic force over the pole faces to be obtained. Thus by concentrating the lines of force near the middle of the pole face, they become more effective in producing alternating voltage and the ratio of alternating to direct-current voltage is increased, since the direct-current voltage is dependent

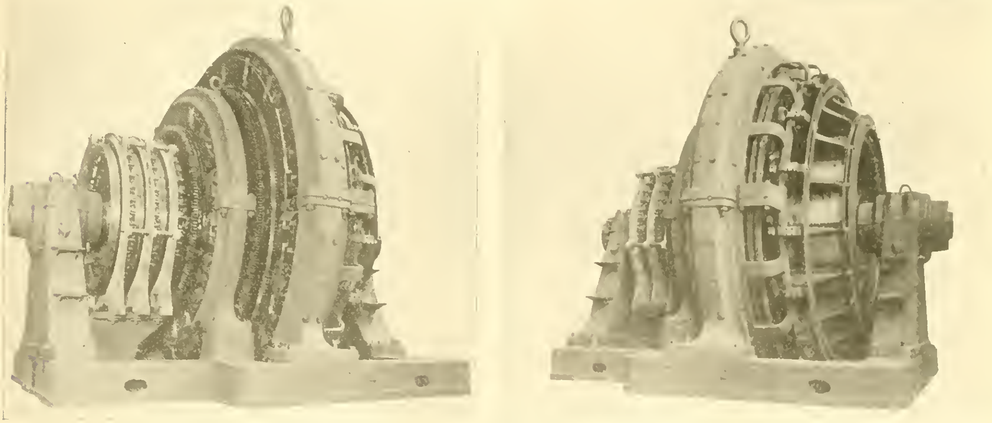


FIG. 1—1000 KW, 275 VOLT, 167 R.P.M. BOOSTER CONVERTER
One of 10 duplicate units built for the New York Edison Co.

only on the quantity and not the distribution of the lines of force. Conversely by concentrating the field flux at the tips of the main poles, the ratio of alternating to direct-current voltage is reduced. The advantages claimed for this system over the reactance control system were improvement in armature heating, power-factor, efficiency and regulation of the alternating-current apparatus and transmission lines, as well as greater stability of the converter itself due to the absence of wattless currents.

It was not until about 1904 that the split-pole converter was introduced commercially in industrial service. As a competitor of the then existing types of converters it embodied certain advantages but it possessed inherent commutating defects which caused it to become obsolete within a few years. Non-commutating pole converters require a commutating field or "fringe" from the main field poles in order to commutate successfully and the principle on which the split pole converter operated made this a difficult condition to maintain.

A modification of the original booster type converter was introduced by the British Westinghouse Company in 1904 and was being built in this country by 1906. It consisted of a small alternating-current generator, usually of 15 percent of the converter rating, connected in series with the alternating-current side of the converter and having its field excitation so controlled as to permit any desired variation of direct-current voltage independent of the direct-current load. The converter armature was free from wattless currents over its entire voltage range, and the power-factor could be maintained at unity at all times. From the commutation standpoint the booster type non-commutating pole unit had no inherent defects, and in general proved a very popular and widely used type of machine, many units still being used successfully in commercial lighting service.

Between 1906 and 1911 the split-pole and booster type converters were competitors for industrial power supply, when the adaptation of commutating poles in converter design about 1911 settled the question of their relative merits. Owing to the complicated magnetic structure of the split-pole converter it is not practicable to make an ideal application of commutating poles that are inherently self-adjusting, while with the booster type converter the addition of commutating poles presents no theoretical difficulties and relatively little complication. Coincident with the introduction of commutating poles, the speeds of converters were greatly increased, resulting in a reduction in cost and floor space and at the same time greatly improving the commutating characteristics. The facility with which the booster-type machine lent itself to the incorporation of these new developments accounts for its survival over other types possessing less flexibility.

The booster-type converter has successfully met all of the operating requirements of the three-wire Edison service; its operating voltage range has usually been considerably in excess of the normal service requirements, allowing a conservative margin for unusual operating or power supply conditions; its record for consistent, safe operation and entire freedom from coil burn-outs has been due to the relatively equal distribution of its armature copper losses when working at its extreme limits of voltage range; its total efficiency, considering the losses in the converter, transformer, transmission line and generating apparatus, is equal to if not better than that of any system requiring large wattless currents from the high-tension line to accomplish its voltage control; its characteristic of operating at all loads and all voltages at 100 percent power-factor on the high-tension line makes it a most desirable central station load, especially when a premium is frequently offered for loads of high or leading power-factor characteristics; its extreme flexibility in having its power-factor control independent of the load and voltage control, and the facility and absolute safety with which the converter may be direct-current started and synchronized onto the alternating-current line without any momentary surge of current at time of switching onto the line, regardless of the value of the direct-current voltage; all of these and possibly many minor characteristics are tangible assets of the booster type converter that are responsible for the safe and consistently satisfactory record of service that this type of machine has given since its introduction.

Continued concentration of power consumption in the large industrial centers has brought about a condition analogous to that pertaining at the time the electrical industry was first established. On many Edison systems there is a certain constant magnitude of power demand, located adjacent to the central power distributing stations which may be supplied with power from a central station bus having but a relatively small variation in potential over the entire day. Most large Edison systems maintain three direct-current voltage busses fed by converters, all of which have the same alternating-current voltage. At times of light load the three busses are close together in voltage, while at times of heavy load the bus voltages vary widely, depending on the requirements of the loads on each circuit. This condition has required the operation of some converters always bucking the direct-current voltage, some bucking or boosting a slight amount and some always boosting.

In the last few years some consideration has been given to the possibility of supplying that portion of the central station load which normally requires only a small range of voltage control, from single converters, obtaining the small required voltage range by reactance control with wattless currents. The advantages to be obtained are reduced first cost of the converter, a saving in floor space which is frequently important, and a

simplification of the converter itself due to the omission of its booster and its control. The reactance controlled type converter has some operating characteristics of a radically different nature from those of the booster type machine and a discussion of these features may be of interest:—

Method of Obtaining Voltage Range—Speaking in general terms, a converter which has a full load and a two hour 50 percent overload rating may ordinarily be operated safely with at least 30 percent leading or lagging wattless current at full load, as under these conditions the average armature heating is increased 30 percent and the tap coil heating is increased 80 percent. Any voltage range desired may then be obtained at full load by using a reactance of the proper magnitude in the alternating-current circuit, since the available voltage range is the product of the percent reactance times the percent wattless current in converter armature. With 30 percent wattless kv-a. a voltage range of five percent up and down requires a 16.6 percent reactance while a 7.5 percent voltage range requires 25 percent reactance.

TABLE I—REACTANCE CONTROLLED CONVERTER

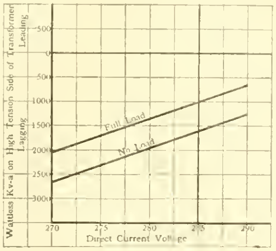
Transformer		Converter Arm. Wattless		H. T. Line Wattless Kv-a		
Mag. Kv-a	React. Kv-a.	Boost	Buck	5% Boost	Mid. Voltage	5% Buck.
5%	16.6%	30% Lead	30% Lag	8.4% Lead	21.6% Lag	51.6% Lag
5%	33%	15% Lead	15% Lag	23% Lag	38% Lag	53% Lag

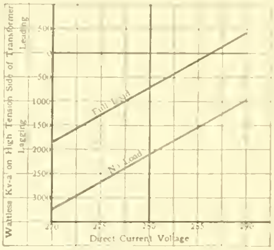
Limits of Voltage Range—The factors which limit the voltage range are (1) the maximum amount of wattless current it is safe to carry in the converter armature, from the heating standpoint of both armature and field windings, and (2) the reactance available. Having settled on a safe maximum percent wattless kv-a. for a given converter armature, the voltage range at any constant load is limited only by the percent reactance installed and the quantity of wattless kv-a. it is desirable to draw from the high-tension line—by the ability of the generators, lines and transformers to carry additional current represented by the low lagging power-factor. For any given voltage range the converter armature may be favored by using a small wattless current and a high transformer reactance resulting in a large total wattless kv-a. in the high-tension line, or the high-tension line may be favored by drawing a large wattless current into the converter armature and using a small reactance, thereby requiring a smaller wattless kv-a. from the high-tension line. These two conditions may readily be illustrated by Table I, where a five percent up and down voltage range is required. The booster type converter which normally is supplied from a five percent reactance transformer and is guaranteed for 100 percent power-factor on the high-tension side works under the corresponding conditions given in Table II.

TABLE II—BOOSTER CONVERTER

Transformer		Converter Arm. Wattless		H. T. Line Wattless Kv-a		
Mag. Kv-a.	React. Kv-a	Boost	Buck	5% Boost	Mid. Voltage	5% Buck.
5%	5%	10% Lead	10% Lead	0%	0%	0%

The High-tension Line Power-Factor Characteristics—From the foregoing it is evident that the simple non-booster converter works over its voltage range by requiring a large range of wattless kv-a. from the high-tension line as a fundamental condition. Fig. 2 shows the high-tension line wattless kv-a. on a 4000 kw converter for an assumed voltage range of 270 to 290 volts, using a reactance of 20 percent and a mid voltage of 285 volts. Fig. 3 shows the high-tension line wattless kv-a. for the same voltage range, 270 to 290 volts, with 280 volts mid voltage and with a 12.5 percent reactance. These two conditions are shown to illustrate the variation in high-tension line power-factor





FIGS. 2 AND 3—CHARACTERISTICS OF 4000 KW NON-BOOSTER CONVERTER TRANSFORMER UNIT

Fig. 2—20 percent reactance, 5 percent magnetizing, 4 percent internal converter drop, and 3 percent transformer regulation. Fig. 3 12.5 percent reactance, 5 percent magnetizing, 4 percent internal converter drop and 2 percent transformer regulation. Constant high tension voltage in both cases.

that it is possible to obtain, depending upon the magnitude of the reactance used and the extent to which the converter is worked in wattless current. In the first case, at full load the converter armature carries only nine percent leading current at 290 volts and 26.5 percent lagging current at 270 volts, leaving heating capacity in the converter armature for additional leading current and increased voltage boost to offset any high-tension voltage variation that would tend to reduce the voltage range; in the second case the converter armature carries 28.5 percent leading current at 290 volts and 28.5 percent lagging current at 270 volts. The converter with the greatest wattless current and armature heating has the superior high-tension power-factor. At no load the converter armature wattless current is very considerably in excess of these figures. The prevailing power-factor characteristic on the high-tension line is thus shown to be lagging over the greater part

of the voltage range of even the most favorable of the two examples. A converter having poor high-tension power-factor characteristics, such as Fig. 2, has a large permissible voltage range, while one having improved high-tension power-factor characteristics, such as Fig. 3 has very reserved voltage range for any contingency. Flexibility in this respect is obtained at the expense of low power-factor on the high-tension line.

Effect of High-tension Line Voltage Variation—On a simple non-booster type converter, having a relatively small voltage range, any variation of high-tension voltage may become a large percentage of the converter voltage range and must be subtracted directly from the voltage range obtainable with constant high-tension voltage. In making any commercial installation, some allowance must be made for such a contingency, and if this high-tension voltage variation is likely to take the form of a drop in voltage, it means that the upper voltage range will be unobtainable to the extent of high-tension line voltage variation, unless the converter is worked at additional wattless current during this time. Unless the power company has absolute assurance against even small high-tension voltage variations, it would be unsafe to install a simple converter that was worked up to its limiting amount of wattless current at full load maximum voltage. There should be a margin for over-excitation for time of low high-tension voltage in order that the full voltage range can be maintained.

Efficiency—The simple non-booster converter, at the middle point of its voltage range, has a higher efficiency than the booster converter, due to the omission of the booster and its losses. The magnitude of this difference in efficiency may however be quite small. For the 4000 kw converter with a 35 volt up and down range the losses in the booster at full load are less than 0.4 percent. The machine efficiency itself is not, however, the total efficiency of the converter and transformer as a unit, and it is the total efficiency of the unit which is of greatest importance. The simple non-booster converter works at a considerable lagging power-factor on the high-tension line over the greater part of its voltage range and the losses in the transformer, transmission line and power house generating apparatus incident to supplying this lagging wattless current must logically be charged against the efficiency of the simple non-booster converter unit. The manufacturer is not in a position to know the losses in these external elements due to this condition, but it is evident that a mere statement of machine efficiencies does not tell the entire story. As the power company is primarily interested in power house coal consumption, it should consider the total losses involved when operating this type of converter and include them in the converter efficiency. It is believed that an efficiency comparison on a proper basis will show the booster type machine, when operated at 100 percent power-factor on the high-tension line, to possess features of economy that may not be evident on casual examination.

Comments on Power-factor Measurements—In discussing the wattless kv-a. that a single non-booster type converter requires to accomplish its voltage regulation, it has become customary to refer to the wattless kv-a. at the converter terminals rather than the wattless kv-a. on the high-tension side of the transformer. This method ignores some 20 percent of the machines' rating in wattless kv-a., due to the transformer reactance and some five percent due to the transformer magnetizing kv-a., a total kv-a. of 25 percent which should be considered in discussing the power-factor of the unit. The present practice among power companies of connecting the wattless component indicator with its current element on the high-tension side and its voltage element on the low-tension side of the transformer does not include the transformers 20 percent reactance kv-a. on the meter reading, a fact that should be kept clearly in mind when receiving data on tests on the power-factor characteristics of converters. With the booster type unit, using a five percent reactance transformer, the discrepancy between the meter reading and the high-tension power-factor is correspondingly much less.

Facility of Starting—With alternating-current self starting there is no material difference between the two types of machines as the same control apparatus is required for starting both of them. With direct-current starting there is a decided handicap in getting simple non-booster machine on the direct-current bus at times of heaviest station load and maximum direct-current voltage. This condition arises because of the absence of any control of voltage on the collector side of a direct-current started converter, until the machine is switched on to its high-tension line and can draw in wattless currents. At this time the direct-current bus voltage is considerably above normal and the collector ring voltage of a direct-current started simple converter is much higher than that of the incoming line. Because of the absence of voltage control it is necessary to switch the converter onto the alternating-current system with this difference in alternating-current voltage existing, thereby drawing a heavy reversed flow of current from the direct-current system at a time when it is already heavily loaded.

Commutation Control—Converters of usual design operated off unity power factor do not commutate perfectly, and if commutator and brush maintenance expense is not to be increased in this type of unit, its commutation performance must be maintained up to the usual standard by commutation control devices, either automatic or manual. The device on the converter will be a small coil on the commutating poles identical with that on the present booster type machine, with a control only slightly modified.

The above mentioned features are the major ones wherein the booster and non-booster type machines have different characteristics. These characteristics are almost entirely of an operating nature and should receive the careful consideration of operating engineers.

Adjustable Laboratory Rheostats

THOMAS SPOONER

VARIOUS types of adjustable rheostats are available which are excellently adapted to certain purposes. None of these, however, are altogether satisfactory for many laboratory needs and three new types have, therefore, been developed which have proved widely useful, each in its own field.

LAMP BOARD RHEOSTAT

This rheostat is a very compact portable lamp board with a fine adjustment feature. On one side of a vertical board, Fig. 1, are placed as many lamp sockets as desired and directly opposite on the other side of the board are placed single-pole, double-throw baby knife switches, (one more switch than there are lamp sockets). All of the top switch break jaws are connected by a bus to one binding post *B*, Fig. 2, and the bottom jaws to the other binding post. A lamp is connected between each pair of switch hinge jaws. A small slide rheostat having a resistance slightly greater than that of one lamp is connected in series with the right hand lamp.

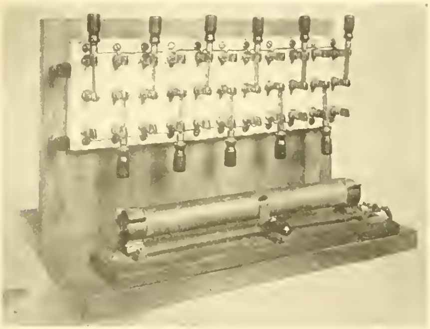


FIG. 1—LAMP BOARD RHEOSTAT

By throwing the first switch up and the last one down, with the rest open, all of the lamps are connected in series, giving the maximum resistance. By closing all the switches alternately up and down, the lamps are thrown in parallel, giving the minimum resistance. By proper manipulation of the switches, any series-parallel connection desired may be obtained. If the right hand lamp is kept always in circuit, the rheostat *R* makes it possible to obtain any fine adjustment desired, between the steps produced by the change of one lamp. Due to the arrangement of lamps and switches, the wiring is very simple and direct, and practically none is exposed.

VERTICAL SLIDE RHEOSTAT

Several types of slide rheostats are available but the type to be described has several novel features. The rheostat is arranged for mounting in a vertical position as shown in Fig. 3. A seamless steel or brass tube is sawed out at the bottom and four legs formed from the tube material, no casting or extra parts being required for a base. The legs are drilled so that the rheostat may be screwed down if desired. The tube is then enameled or other suitable insulating coating applied and wound with oxidized resistance wire or ribbon such as 30 percent nickel steel, "nichrome", or "advance". The advantage of "advance" is that it has practically a zero temperature coefficient of resistance. Before winding, the wire is treated in a furnace with an oxidizing atmosphere to form a resistance coating. This may be done by putting a roll of wire in a red hot furnace for a few minutes or a tube furnace may be used and the wire drawn through at a slow rate.

The sliding contact, Fig. 4, consists of a molded insulation ring having an internal groove containing a helical spring which surrounds the rheostat tube. This spring is connected to a binding post. After placing the slide in position, the ends of the resistance wire are fastened to suitable end terminals.

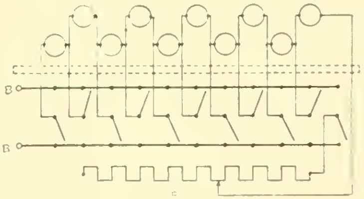


FIG. 2—WIRING DIAGRAM OF LAMP BOARD RHEOSTAT

If "advance" wire is used, the proper size for a given resistance may be calculated by assuming a specific resistance of 294 ohms per circular mil foot. If a rheostat has been built with any given size of wire, the resistance of another range may be calculated by assuming that the resistance varies inversely as the cube of the diameter of the wire. This is not strictly true however since for smaller sizes the oxidation and stretching due to winding increase the resistance.

If it is desired to construct a rheostat on short notice and no enameled tube is available, a fairly satisfactory insulation consists of a layer of asbestos paper moistened with a ten percent solution of sodium silicate. After baking at 100 degrees C., this makes a fairly hard, tight insulating coating but is not as satisfactory as the enamel, due to its lower thermal conductivity.

The advantages of this type of rheostat are:—

1—The vertical arrangement gives a chimney effect which aids in cooling.

2—The vertical arrangement makes it possible to locate more rheostats in a given space on a test bench.

3—The particular form of sliding contact provides a large number of contact points, assuring good electrical connection and small wear.

4—By tipping the axis of the ring slightly, an adjustment of less than one turn may be obtained.

5—It is impossible for the sliding contact to stick.

COMPRESSION RHEOSTAT

There are several makes of compression rheostats on the market, but so far as we know, they all use either carbon or graphite plates and therefore have a very low resistance and high negative temperature coefficient. The new compression rheostat has a large range, any resistance desired from a fraction of an ohm to many megohms and a considerably smaller negative temperature coefficient than is obtained with carbon or graphite.

FIG. 3—VERTICAL SLIDE RHEOSTAT

The resistance material itself*, is in the form of rings about one inch outside diameter, 5/16 inch inside diameter and 3/16 inch thick. By using the proper mixture, any specific resistance desired may be obtained.

The resistance material is extruded in the form of a tube, given the proper baking treatment and then cut into rings. It has a much lower temperature coefficient of resistance than graphite or carbon. The rings are arranged in three stacks, forming an equilateral triangle, with a copper ring between each pair of resistance rings as shown in Fig. 5. Each stack is supported by a central rod insulated with a glass, porcelain or other suitable insulating tube. The central rods also act as tie rods between the end plates and take care of the thrust produced by the compression screw. This screw applies pressure at the center of the compression plate, thus giving equal pressure for all the stacks.

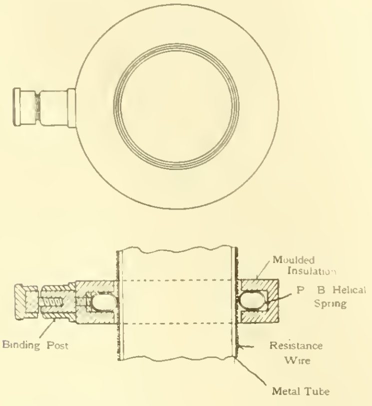


FIG. 4—SLIDING CONTACT FOR VERTICAL SLIDE RHEOSTAT

With the switch S open, Fig. 6, the three resistance stacks are connected in series with the binding posts

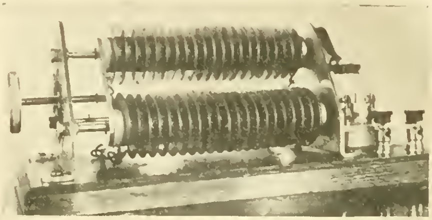


FIG. 5—COMPRESSION RHEOSTAT

P. With switch S closed the three stacks are connected in parallel, thus giving a 9 to 1 range over that obtained by compression alone. In general a resistance range of 200 to 1, and often much more, may be obtained for this type of rheostat. As an illustration of the possible ranges of resistance obtainable, we have one rheostat which can be varied from 60 ohms to 30 000 ohms and another which has limits of from 300 ohms to 400 000 ohms. The rheostats are not very stable at the higher ranges. For reasonable constancy, the second rheostat for instance should not be used for resistances over 100 000 ohms. By the use of the three stacks, each may be made fairly short, so that little or no trouble is experienced from unequal pressure due to friction of the resistance rings on the supporting tube.

TABLE I—CHARACTERISTICS OF THE VARIOUS TYPES OF RHEOSTATS

Type	Capacity Watts	Range*	Limits Ohms	Characteristics	Remarks
Lamp Board	1100	200 to 1**	Limited by lamps available	Non - inductive easily renewable elements	Capacity based on ten 32 c-p carbon lamps
Slide rheostat	500	0 to max.	Min. = 2 Max. = 5000	Zero temp. coef.	"Advance" wire 15 inch tube
Comp. rheostat	500	200 to 1	Min. = 1 Max. = megohms	Non-inductive	Special resistor material

*Range is for a given rheostat.
**This range is obtainable with carbon lamps running cool on series connection.

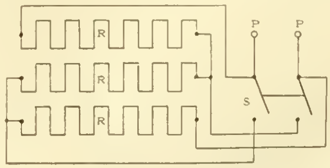


FIG. 6—WIRING DIAGRAM FOR COMPRESSION RHEOSTAT

The copper rings serve three purposes:—

1—To conduct away the heat, thus increasing the capacity or decreasing the change in resistance for a given current due to the heating.

2—To equalize the heat over the surface of the resistor, thus reducing the possibility of permanent changes in the material due to minute local hot spots.

3—When made in saucer form, they prevent a broken

*Which was developed by Mr. G. M. Little of the Research Department of the Westinghouse Electric & Mfg. Company.

ring from falling out. A broken ring, if it remains in position, is as satisfactory as a whole one, since the breaks are always normal to the surface.

If a rheostat is to be operated for any length of time at high capacity, the rings should be of a metal which will oxidize less readily than copper, such as nickel or nickel plated copper. A rheostat of the size shown, having stacks eight inches long, will absorb about one-half kilowatt continuously.

The chief advantages of this type of rheostat are:—

1—Practically non-inductive.
2—Large capacity.
3—Low temperature coefficient.
4—Large range of variation.
5—Any order of resistance desired.
6—Good constancy due to short stacks.
7—Compactness.

These three types of rheostats should meet almost any laboratory needs except where it is necessary to absorb energy of the order of one kilowatt or more.

A Vector Diagram for Salient-Pole Alternators

E. B. SHAND

IT IS well understood that the ordinary vector diagram as applied to synchronous machines fails to take into account the effect of salient-pole construction. In most cases this is of no great moment; but where the stability of a machine operating at greatly reduced excitation is in question, the results obtained from the diagram are so widely astray that some modification is desirable.

Ordinarily, synchronous machines do not operate with reduced excitation, but occasionally when supplying a load of high inductive capacity, such as an unloaded high-voltage transmissive line, the condition exists. In the case of synchronous condensers it has even been contemplated to operate with a small amount of reversed excitation to counterbalance the leading reactive currents. A modified vector diagram, which might be called an elliptic vector diagram is therefore suggested for use in determining the stability of a salient-pole synchronous machine for such operation.*

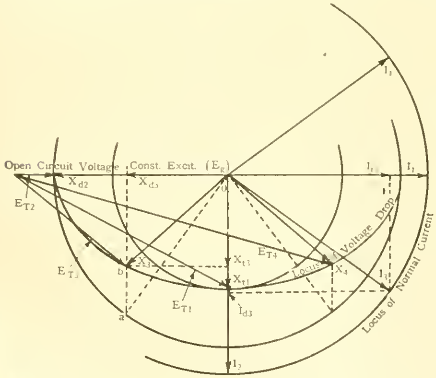


FIG. 1—ELLIPTIC VECTOR DIAGRAM FOR SALIENT-POLE ALTERNATORS

I_1, I_2 — armature currents; I_{t3}, I_{d3} — transverse and direct components of I_3; X_3, X_4 — total reactive e.m.f.; X_t, X_{d2} — transverse and direct components of reactive e.m.f., and E_{T1}, E_{T2} — voltage at terminals.

Blondel showed in his various writings that the non-uniformity of the reluctance of the magnetic circuit due to the salient-pole construction causes a variable reactive effect of a given armature current, depending upon whether its m.m.f. acts directly opposite the poles or opposite the interpolar spaces. In the former case the reactive effect is a maximum; in the latter, a minimum. He called these effects, respectively, those of direct and of transverse reactions. The elliptic diagram, then, is based directly on this conception of two reactions and takes into account the variable reactive effect of the current.

In Fig. 1 is shown the elliptic diagram for an alternator. E_g represents the open-circuit voltage for a given excitation, and is always generated in the conductors directly under the poles. I_1 is a current in phase with E_g. It will have a minimum reactive effect X_{t_1} because its m.m.f. is opposite the interpolar space. The terminal voltages is E_{T1}. A current I_2 displaced 90 degrees from E_g will have a maximum reactive effect X_{d_2}. A corresponding current in any intermediate phase position, say I_3, may be resolved into two components, one in phase with I_1, and the other with I_2, viz., I_{t_3} and I_{d_3} producing the transverse and direct reactive effects X_{t_3} and X_{d_3} with a combined effect X_3. The locus of this latter reactive voltage, when plotted, is found to be the ellipse so designated on the diagram. It will be noted that the current I_3 produces a reactive drop X_3 in the machine which is not proportional to the current alone, and is dispaced 90 degrees from it only when the current coincides with one of the two axes of the ellipse.

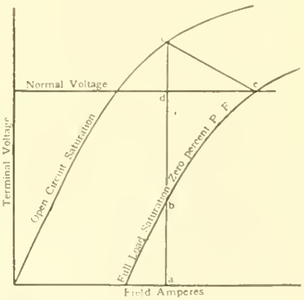


FIG. 2—NO-LOAD AND ZERO POWER-FACTOR LOAD SATURATION CURVES

*This type of diagram was, so far as the writer knows, first proposed by Mr. F. Creedy, a British engineer, in the *Journal of the Institute of Electrical Engineers* 1915-16, p. 427.

In the actual use of the diagram, it is necessary to determine the major and minor axes in order to draw in the ellipse. When this is done a current may be assumed, say I_3, and oa drawn at right angles to it, cutting the circle with a radius equal to half the major

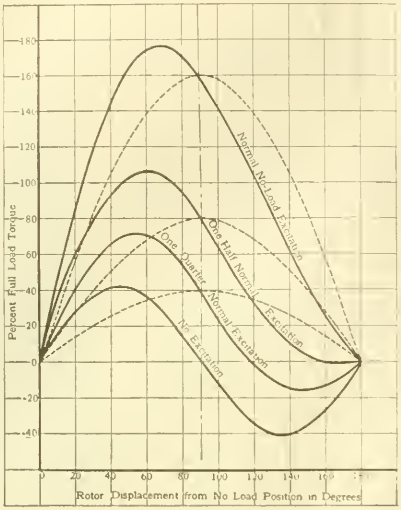


FIG. 3—DISPLACEMENT OF ROTOR FROM NORMAL POSITION FOR ANY TORQUE

axis at a. Then, by dropping the perpendicular ab to cut the ellipse at b the reactive drop ob or X_3 is obtained.

The major axis is readily determined from standard test data just as it would be for circular vectors. Let Fig. 2 represent the open-circuit saturation curve and full load saturation curve at zero percent power-factor of an alternator. For the excitation a, draw the intersecting perpendicular bc which may be divided by the use of Potier's triangle. This triangle gives a method for dividing the total effect of the armature current at zero percent power-factor into the components of armature reactance and armature reactions*. Thus in Fig. 2, cd represents the armature reactance voltage and dc the equivalent magnetizing field current needed to overcome the armature reaction. Each of these is then considered to be proportional to the current. The armature reaction e.m.f. is, therefore, represented by bd. For this condition the major axis will be bc. The ratio of transverse reaction to direct reaction for any machine may be obtained from calculations. For usual proportions for salient poles at fairly low saturations it may vary from 55 to 60 percent, depending mainly on the ratio of pole-arc to pole-pitch. In the present case the minor axis may be assumed to be $0.55\ bd + dc$. The reactance drop dc is assumed to be independent of phase position. The remainder of the construction is quite similar to that for ordinary circular vectors.

The displacement of the rotor from the normal position for any torque is expressed in Fig. 3. The curves are drawn on the assumptions that the ratio of one axis to the other is 0.65 and that the short-circuit ratio of the machine is unity. It will be noted that in every case the maximum torque is reached before the rotor-displacement has increased to 90 electrical degrees, and further that each curve may be considered as the combination of two others—that of torque with no excitation and a respective dotted curve. The dotted curve is one obtained from the ordinary circular vector diagram, assuming a synchronous reactance corresponding to that expressed by the minor axis of the ellipse.

Fig. 4 represents the line of the maximum torques replotted from figure 3. The dotted curves in either case are supposed to apply to a turbine-generator with a smooth rotor. The two curves give an indication of the relative stabilities of the two types of machines.

When the case of a synchronous condenser with no mechanical load is considered, the steady torque necessary to operate the machine is inappreciable. The operation, however, may become unstable before the reversed excitation is increased to any considerable extent, because the synchronizing torque necessary for stability may be greatly in excess of the steady value. This is equivalent to saying that the torques resisting the action of hunting become decreased to such an extent that it is difficult to prevent the machine from slipping a pole during any incidental disturbance. This can

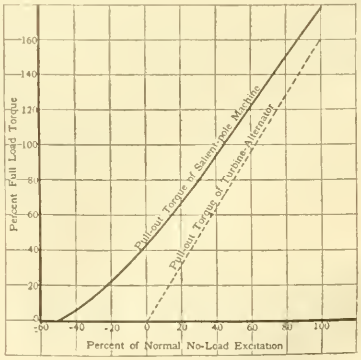


FIG. 4—LINE OF MAXIMUM TORQUES REPLOTTED FROM FIG. 3

be seen from the negative torque values of Fig. 3, which represent the operation on reversed excitation.

The effect of saturation has been neglected; it will tend to reduce the difference between the two axes of the ellipse. This may be allowed for, although the resulting difference is not great for a machine of normal design.

*See "Regulation of Definite Pole Alternators" by S. H. Mortensen, *Transactions A. I. E. E.*, February, 1913.

Typical Relay Connections-II

LEWIS A. TERVEN

WHEN the neutral point of a group of star-connected generators operating in parallel is to be connected to ground, it is important that only one generator be grounded at a time, in order to avoid circulation of third harmonic currents. It is usually necessary, however, to provide a connection to ground through a circuit breaker from each of the generators, in order that any generator may be operated singly at times of light load. In such cases, it is desirable to have some form of relay interlock, so that if the operator attempts to close a ground circuit breaker when another is already closed, the incoming circuit breaker will automatically trip out any other that is already closed.

An example of this application of relays is shown in Fig. 5, the circuits of which can be traced by assuming that any one of the circuit breakers, for instance, the one on the left hand, is to be closed. Positive control current will flow through wire *S* to wire *Y* which is negative, closing the oil circuit breaker, which in turn will cause the auxiliary or pallet switches to assume the upper position. The interlock relay will then be energized, tracing the positive through wire *G*, the right hand pallet switch, the operating coil and the main contacts to wire *Y* which is negative, causing the plunger of the relay to rise, which in turn opens the main contacts and closes the auxiliary contacts, breaking its own circuit in the coil as has been previously explained. Due to the oil dashpot time element device, several seconds will elapse after the coil is energized before the main contacts will be broken. It is thus seen that any circuit breaker which is in circuit will have its relay set with open main contacts and closed auxiliary contacts.

Now assume that the operator closes circuit breaker No. 2. When the auxiliary switches rise to the closed position as before, the operating coil of the interlocking relay belonging to circuit breaker No. 2 which has just been closed will be energized, but some time will elapse before the main contacts are open and the auxiliary contacts close. Meanwhile a circuit is established over wire *G*, positive of the second breaker, through a pallet switch on the circuit breaker to wire *G* of the cross wires in the diagram and on through the trip coil of the first circuit breaker, through the pallet switch of the first breaker, the auxiliary contact of the first breaker's interlocking relay, to negative, causing the first breaker to trip. An examination of the diagram will show that no matter which circuit breaker may be closed, any incoming breaker will trip the one which is in service. As soon as any circuit breaker opens, the return of the pallet switches to the lower position makes a circuit from positive through the latch release coil to negative which will cause the relay plunger to return to its normal or lower position with the main contacts of the relay closed and the auxiliary contacts open.

Still another purpose for which the relay described in the preceding diagrams can be used is shown in Fig. 6, where a flexible connection from the main contact bridge is connected to a binding post which leads to an annunciator drop. With this design the bell can be used for a number of breakers, while an annunciator drop is provided for each relay. In some cases each panel controlling two circuit breakers is provided with an annunciator drop and in some cases a relay is provided for each breaker, so that an annunciator signal may be given to the chief operator for each breaker of the system. The same relay can be used for signal lamp pur-

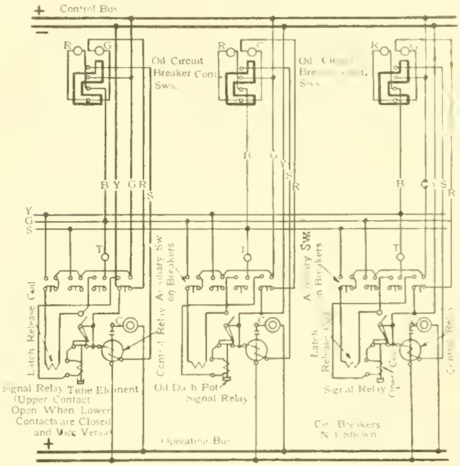


FIG. 5—CONNECTIONS OF RELAY FOR INTERLOCKING GROUND CIRCUIT BREAKERS

poses and in some cases the auxiliary contact shown in Fig. 5 is added, being used in connection with certain features of the circuit breaker control.

Reference has previously been made to the fact that when the operating circuit of the direct-current auxiliary relays must be kept separate from the individual circuits which are to be made by the relay, additional segments on the control switches will not answer the purpose. Multi-contact relays such as shown in Fig. 8 are admirably adapted to the end in view, and applications will be given later. The relay contacts close instantly when the main coil is energized and open immediately when the coil is de-energized. One exception to the above occurs with the multi-contact relay (*d*) which has one finger for making a contact for bell alarm purposes. This finger will remain in the closed position when operated until mechanically re-

leased by a small push button which opens the contact against friction. In cases of large systems where the control circuit for the different busses are kept separate, multi-contact relays are very serviceable and they are also of use in differential protection of apparatus where an internal failure requires the isolation of the machine involved, removing all sources of incoming or outgoing power from it. In relay (*d*) one set of contacts opens as the other three close, and vice-versa.

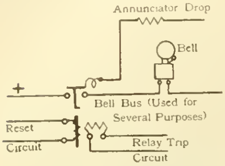


FIG. 6—BELL ALARM RELAY WITH ANNUNCIATOR CONTACTS

A relay whose application is the reverse of that shown in Figs. 1 to 4, is shown in Fig. 7. The purpose of this relay is to open the circuit instantly upon an impulse passing through its operating coils, the circuit thus established being interrupted by the pallet switch of the circuit breaker. Once the circuit through the coil is interrupted the main contacts of the relay will slowly settle into the closed position, a definite time elapsing as determined by the setting of the small dashpots indicated in the diagram. The general use of this relay is to interrupt a companion circuit until the function of the first circuit is completed. For example, where a short-circuit occurs on one of two parallel transmission lines, it is desirable to prevent the operation of the circuit breakers on the other line until after the breakers on both ends of the short circuited line have opened, thereby clearing the fault.

A reverse-power direct-current relay is shown in Fig. 9 which is instantaneous in operation. It consists of a stationary potential coil which produces a magnetic field in which is a movable current coil connected across an ammeter shunt. The moving coil carries contacts for closing an auxiliary direct-current control circuit. This relay is essentially a wattmeter which is mechanically prevented from moving in the positive direction but closes its contacts quickly upon a reversal of the direction of power flow. By the use of double contacts, this same relay can be arranged to close a second circuit in the reversed direction. Such an instrument is very sensitive to the potential drop in the shunt and the moving coil can be so wound as to cause tripping at very low values of potential difference at the shunt. However, for positive operation, ample potential difference is desirable, the high resistance shunt being used or sometimes a section of the main conductor of the circuit.

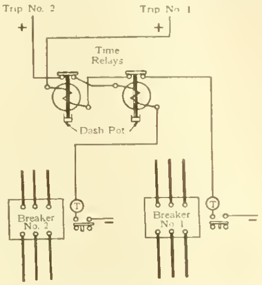


FIG. 7—CONNECTIONS OF RELAYS FOR OPENING ONE CIRCUIT INSTANTANEOUSLY

Operation of one circuit breaker prevents the other circuit breaker from tripping until time interval has elapsed.

This relay is quite sensitive and is used with electrically operated circuit breakers for reverse power operation. For mechanically operated circuit breakers, such as the usual type of carbon circuit breaker, the type of relay shown in Fig. 10 is applicable. For ordinary reverse current application the overspeed device should be considered as having its contact closed. The two coils in each shunt circuit are wound for opposite polarities and the polarities of the upper coils are reversed from the lower ones, so that the diagonal coils are of the same polarity. A coil in series with the carbon circuit breaker, not shown in the diagram, assists the magnetic flow through the lower coils and bucks that through the upper coils, keeping the armature in its lower position. A reversal of current in the series coil causes it to buck the flux in the lower shunt coils and boost that in the upper shunt coils, lifting the armature and tripping the circuit breaker. The field strengths are adjusted so that a relatively small reversed current is sufficient to cause the circuit breaker to trip.

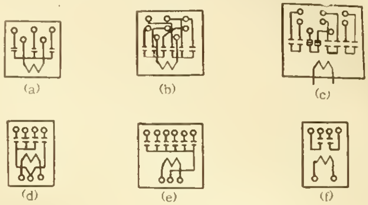


FIG. 8—MULTI-CONTACT RELAYS

(a) Three contacts; (b) Six contacts; (c) Eight contacts, two opening and six closing; (d) One finger held latched requiring manual release; (e) Six contacts; (f) Two circuits.

The overspeed device, which is not an essential part of the reversed current attachment, is used on synchronous converters to prevent their attaining a destructive speed upon reversal of power. It operates to interrupt the shunt circuit through the lower pair of coils, permitting the upper coils to lift the armature and trip the circuit breaker. Overloads are cared for by an entirely separate series coil which trips the circuit breaker on overloads only. It should be noted that the auxiliary pallet switch used with carbon circuit

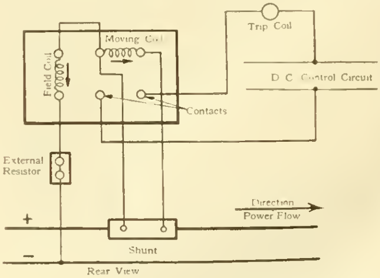


FIG. 9—DIRECT-CURRENT REVERSE-POWER RELAY

breakers is shown reversed from the symbol used for oil circuit breakers. This fact should be borne in mind in connection with the diagrams which follow.

Carbon circuit breakers are usually provided with internal overload tripping devices, and they may also be equipped with low voltage coils which will trip the latch upon failure of voltage. Fig. 11 shows an overload direct-current relay arranged to disconnect all of the carbon circuit breakers connected to that circuit, by opening the low-voltage circuit of the circuit breakers, the pallet switches being in series with the low-voltage coils. Although this latter arrangement is common, usually no useful result is accomplished, because in case of low-voltage, the amount of current to be interrupted in the low-voltage coils is quite small. If the overload relay should operate there would be no current to be broken by the pallet switches. On the other hand on the return of voltage to the circuit the pallet switches will prevent this voltage from being impressed upon the low-voltage coils while the circuit breakers themselves are open.

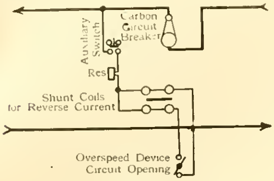


FIG. 10—REVERSE CURRENT TRIP

An application of the relay shown in Fig. 9 for temperature control purposes is shown in Fig. 12. This relay serves to control the operation of a motor driven blower which forces air through the circulating system of the machine in which a search coil is embedded. The operation of the temperature relay system is as follows:—The search coil forms one leg of a wheatstone bridge which is balanced at normal temperatures, so that only small amounts of current will flow through the relay. The resistance of the search coil increases with its temperature, so that at a predetermined high temperature the bridge will be enough unbalanced to send a sufficient current through the relay to cause the contacts on the high temperature side to close. It is obvious that the contacts of the temperature relay must be quite sensitive and of the floating type. For this reason an auxiliary relay must be installed which will fulfill two objects; first to handle the larger current which is required for the control of the blower motor, and second to give a positive operation which will cause the switch to stay in the closed position until the temperature relay has reached the other extreme of its travel and thus shut off the blower motor when the temperature has been reduced to the lower limit. The current may be traced from the positive control bus to binding post *6*, through the relay contact to binding post *5*, through the right-hand auxiliary relay coil to the left-hand toggle switch contacts and thence to the negative control bus. This operation will close the contact of the auxiliary relay, causing the blower motor to operate, and at the same time the toggle switch will be moved to the right-hand position, which leaves the right-hand coils of the auxiliary relay disconnected. This means that any further chattering of the temperature relay contacts will produce no current in the right-hand coil. When the temperature becomes sufficiently low to allow a circuit to be established through binding post *6*, contacts of the relay, binding post *7*, left-hand coil of the auxiliary relay and right-hand side of the toggle switch, when the auxiliary relay will open its circuit and the toggle switch will be set back to the left-hand position. For accurate operation of such a system it is desirable to have the control circuit at a constant voltage, because the amount of current which flows in the movable contact of the temperature relays, as well as in the permanent coil of this relay, is directly proportional to the voltage of the direct-current control circuit.

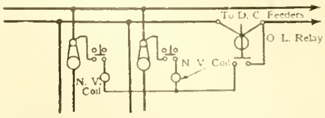


FIG. 11—CONNECTIONS FOR DIRECT CURRENT OVERLOAD RELAY

An interesting diagram exemplifying the use of a sequence relay is shown in Fig. 13. The object of the sequence relay is to prevent the operator from connecting a motor across full line voltage, without having gone through the starting position, and it furthermore reduces the time interval between the opening of the starting breaker and the closing of the running breaker to a minimum.

A special motor starting control switch is shown, the first operation being to short-circuit the two upper left-hand contacts which will cause negative control current to be impressed upon the tripping coil of the running circuit breaker, so that should the latter be closed it will be tripped. The desirability of this contact may be seen from the fact that the operator through accident might attempt to throw a motor into the starting position when it was already running. In the second position all three of the left-hand contacts of

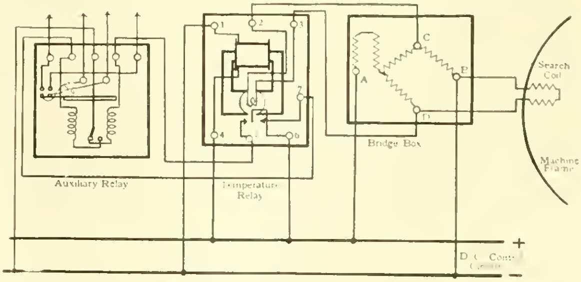


FIG. 12—CONNECTIONS FOR TEMPERATURE RELAY

the control switch will be short-circuited and negative control current will pass over wire *CS* and through the open position of the pallet switch of the running breaker to positive, causing the control relay of the magnetizing and starting breakers to operate, the closing coils of the latter two breakers being connected in parallel. The pallet switch interlock of the running breaker is an additional safeguard against closing the starting equipment when the running breaker is in. Upon the magnetizing and starting breakers going into the closed position the pallet switches rise to the upper contacts thereby establishing a circuit from the positive control bus through the coil of the interlocking magnet switch or sequence relay through the upper contacts of the pallet switch, on both the magnetizing and starting breakers, and back to the negative control bus. The interlocking magnet switch closes its auxiliary contacts at the same time that the main contact closes. Now, causes the sequence relay to open, thus completing the operation.

An emergency stop pushbotton is provided to enable the operator to impress tripping current upon the trip coils of all of the circuit breakers of the system, so that should any difficulty arise at any stage of the starting operation, all the breakers can be returned to the open position. It is also desirable to use the emergency stop pushbutton for tripping the running breaker in normal service because, unless the motor starting control switch is provided with a mechanical interlock, it is possible for a careless operator to rotate the left-hand contact too far on the control switch drum, causing the cycle of starting the motor to commence with the resulting temporary short circuit on the motor. The control wires are so numbered and lettered that cables may easily be provided between the switchboard and the breaker compartments as well as between the different

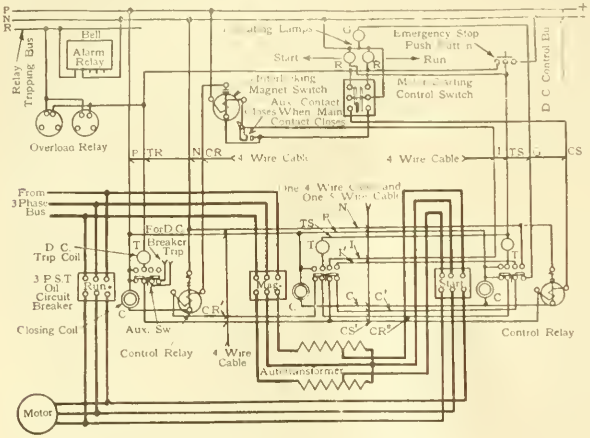


FIG. 13—ELECTRICALLY-OPERATED MOTOR STARTING EQUIPMENT WITH ELECTRICAL INTERLOCK

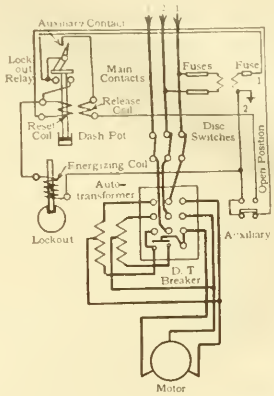


FIG. 14—MECHANICALLY-OPERATED EQUIPMENT WITH LOCKOUT COIL

when the controller is thrown over to the right-hand position, negative current will flow from the lower right-hand stud of the control switch through the auxiliary contact to the coil, of the sequence relay, thereby locking it shut. With the controller in the right-hand position, current will pass from the negative control bus to the upper studs of the control switch over the wire marked *TS* and through the trip coils and pallet switches of the magnetizing and starting breakers, causing these breakers to open. At the same time current will flow from the negative control bus through the lower right-hand stud of the control switch to the main contacts of the sequence relay and through the closing coil of the control relay to wire *CR′*, but the circuit to the positive control bus is not completed until the pallet switches of the magnetizing and starting breakers have both assumed the open position. When this is accomplished, the running breaker will close and the control switch is returned to the normal or open position which breakers of the set. A red lamp lights when any of the circuit breakers is closed, while a green lamp indicates that all three of the circuit breakers are open.

In some cases the oil circuit breakers are rendered fully automatic by the arrangement of the control relays. In such a case the operation of the oil circuit breaker upon closing is to open the main closing coil circuit mechanically by pulling open the clapper of the control relay. At the same time a floating armature is moved into such a position that the magnetic circuit of the control relay is short-circuited and current flowing through the coil of the control relay will produce no effort to close the clapper contact. Under such circumstances the tripping coil of the circuit breaker is free to operate no matter in what position the controller may be.

When the motor is started by means of mechanically-operated circuit breakers, a lockout coil may be used to accomplish the same result as with the electrical

interlock just described. A scheme of this kind is illustrated in Fig. 14 where a motor is started by a double-throw mechanically-operated circuit breaker. The starting position impresses a reduced voltage upon the motor until it comes up to speed and the running position of the breaker impresses full voltage on the motor terminals. A lockout coil controlled by a relay mechanically prevents full voltage being thrown on the motor in case the operator carelessly closes the running side of the breaker without going through the starting operation; and also gives a definite time interval within which the running position must be assumed after throwing out the starting breaker. In case the operator opens the starting breaker and fails to close the running breaker before the time interval has expired, it would be dangerous to connect the motor at reduced speed across the full line voltage, consequently the whole cycle of operation must be gone over again.

Referring to Fig. 14, when the auxiliary switch is open the coils of the lockout relay are not energized. Upon closing the starting breaker the auxiliary switch assumes the upper position, causing current from line *2* to pass through the release coil of the lockout relay, which will open the auxiliary contact and close the main contact of this relay. The main contacts establish a circuit from line *2*, through the lockout coil and the main contacts of the relay, holding the plunger of the lockout mechanism in the raised position, where it will remain as long as current flows in the lockout coils, preventing the closing of the running position. When the starting breaker is opened, current will flow from line *2*, through the lower position of the auxiliary switch and through the reset coil of the lockout relay, and the main contacts to line *1*. The reset coil being energized, the lockout relay will open its main contacts within a definite time, according to the setting of the dashpot, but during the time of suspense the lockout coil is still energized, allowing the operator to throw the motor into the running position. The final condition of all coils will be, as at the start, completely de-energized while the motor is running, or while both starting and running switches are open.

A New Form of Standard Cell

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ALL necessary units for electrical measurements may be defined in terms of the ohm, ampere, volt and second. The ohm is defined, by international agreement, as the resistivity of a uniform column of mercury of a certain weight and length at a given temperature. The ampere is defined as the current which will deposit electrolytically from a solution of silver nitrate a definite weight of silver in a given time. The volt, as at present defined, is derived from the ohm and ampere and is the e.m.f. that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere. This definition of the volt does not supply us with a working standard. The need of a working standard is best met by what is known as a standard cell. Such a cell consists of a suitable positive and negative electrode in an electrolyte. The essential characteristics are permanency, reproducibility and low temperature coefficient.

The Clark normal cell has been the legal standard in the United States since 1894. The positive electrode is a zinc rod and the negative is mercury in a paste of mercurous sulphate and zinc sulphate. The solution is zinc sulphate and the whole is enclosed by a glass container. More recently, it has been found that the Weston normal cell is much superior in all respects. It was adopted by the Bureau of Standards as a working standard in the United States on January 1, 1911. The positive electrode is a 12.5 percent cadmium amalgam and the negative is mercury with a mercurous sulphate and cadmium sulphate paste. The electrolyte is a cadmium sulphate solution. This cell is readily reproducible when sufficient care is taken in the preparation of the chemicals. Several hundred cells of this type have been manufactured by the Bureau of Standards and are held as standards of e.m.f. These standards have been checked against the standard ohm and ampere and against the standards of other National Laboratories. The e.m.f. of this cell is taken as 1.0183 volts at 20 degrees C.

The normal, or saturated cell is not as satisfactory for commercial purposes as the unsaturated, due to the fact that the former has an appreciable temperature coefficient, while the latter has a temperature coefficient of e.m.f. which is entirely negligible for ordinary commercial work. This latter form is the one which is commonly used. It differs from the saturated form only in the concentration of the electrolyte.

The commercial uses of the standard cell are not numerous, but these cells form an essential part of certain types of apparatus as may be judged from the fact that several thousands are sold each year. They find their chief use with potentiometers. The potentiometer is the most accurate method available commercially for measuring voltage, and all high grade instruments have as an essential part, a standard cell as a unit of reference. The potentiometer is usually limited in accuracy only by the accuracy of the standard cell. The accur-

...y of all voltmeters, ammeters, and wattmeters is determined usually by potentiometer tests, as the standard instruments are always calibrated by this means. In many standardizing laboratories, instead of using standard instruments, the voltmeters, ammeters, etc., are calibrated directly by means of potentiometers.

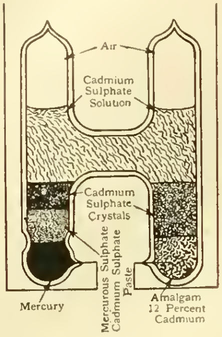

FIG. 1—CONSTRUCTION OF THE H-TYPE CELL

A second very considerable use of standard cells is in connection with thermocouple indicators of the potentiometer type. One of the most accurate methods of measuring temperature is by means of the thermocouple combined with a suitable indicator or recorder. The most accurate indicators work on the potentiometer principle, and contain standard cells as units of reference. Where millivoltmeters are used for indicators, their calibrations are ultimately referred to potentiometer measurements.

From this, we see that most electrical measurements are referred ultimately to the standard cell and depend for their accuracy on the reliability of the cells. Much has been written on the subject of standard cells, and undoubtedly the best combination for great stability is the cadmium cell, as indicated above. The chemicals, Hg | Hg_2SO_4 | $CdSO_4$ (saturated) | Cd amalgam, which enter into its composition may be easily prepared in a pure state, if proper precautions are adopted.

In order to increase the dependability of this type of cell, new materials for the container and leads have been tried and adopted. In order to increase the compactness, the old H-type of cell, shown schematically in Fig. 1, has been abandoned and a concentric type having a diameter of about one in. and a height of about 3.5 in. has been developed.

DEVELOPMENT OF CELL

New Materials—The high percentage of failures of cells of soda glass with platinum leads, of the H-type, led to the selection of another combination of metal and glass. Soda glass has a coefficient of expansion of 8.33×10^{-6}, and platinum 8.99×10^{-6} at room temperatures, so that even well annealed seals often cause leaks or cracks in the glass. Other factors, as the mechanical strength and chemical stability of soft glass, failure of seals due to the zinc amalgam of the Clark cell causing the platinum contact wires to crack the glass, etc., may be cited as reasons why other combinations have been tried. It is obvious that, as leading-in wires, only metals can be used which will be inert to any constituent that the finished cell contains.

The latest design consists of a hard silica glass container which has a coefficient of expansion of 3.50×10^{-6}, and tungsten leads of 3.60×10^{-6}. In selecting a stable hard glass for this purpose a high silica pyrex was chosen. Such glass has been found to be highly insoluable toward the slightly acidic properties such as are encountered in standard cell conditions. Such compositions as sulphur, rosin, sealing wax, etc., make quite an appreciable difference in cell construction. Some of the latter ingredients have been used in certain makes of standard cells for plugs and seals and have shown no drastic ill effects, but where the best equilibria are desired it is advisable not to use them.

In order to make a good tungsten-glass seal it is necessary to clean the metal thoroughly. Boric acid is used for this purpose. A thin coat of B_2O_3 is allowed to remain upon the wire after the fluxing action has taken place. It is necessary to heat the tungsten to a cherry red during the sealing-in of the wire. Most of the thin coat of B_2O_3 is taken up into the glass. Should any be left free upon the wire, it should be completely washed off with water when the cell is cleaned. B_2O_3, as well as other acid oxides occurring in the glass, when taken up by the cadmium sulphate solution has a tendency to depress the e.m.f. of the cell, whereas other oxides in the composition of the glass, such as PbO, ZnO, Na_2O, K_2O, etc., when dissolved in the solution increase the e.m.f. Alumina and silica, as such, have no noticeable effect upon the cell equilibria. However, with the glass used no appreciable effect was observed due to the interaction of the glass with the cell ingredients.

It is interesting to note that the cell contents penetrate the high lead and basic oxide glasses to an appreciable depth, depending upon the time of standing of the cell. By emptying the cell and heating the blank to the temperature of the softening point of the glass and cooling, a definite crazing effect may be observed, that penetrates uniformly to a depth of a few tenths of a millimeter. Similar phenomena are produced by acid treatment and heating of certain glasses.

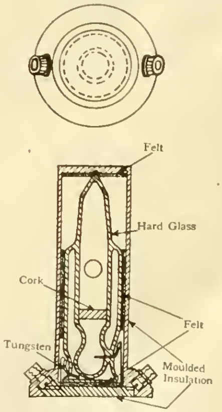

FIG. 2—CONSTRUCTION OF NEW CONCENTRIC TYPE OF STANDARD CELL

The cells made of hard glass with tungsten seals are very strong and durable. No failure of the many cells made thus far can be attributed to the hard glass-tungsten junction, whereas many of the soft glass cells with platinum leads have proven mechanically weak, have crazed or cracked.

NEW FORM

For constant laboratory use, stable portable cells

are needed. The first attempt to produce such a cell resulted in a modification of the H-type which, while an improvement, was later abandoned in favor of the concentric type, which is shown in Fig. 2. The outside dimensions of the concentric cell blank are 2.5 cm. diameter and 10 cm. high. The outer compartment is tubular in form with closed bottom, and is slightly in-

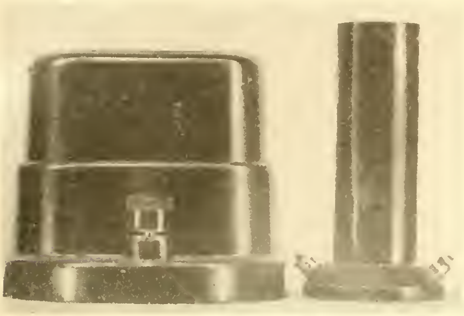

FIG. 3—THE H-TYPE AND THE CONCENTRIC CELLS MOUNTED IN BAKELITE MICARTA CASES

dented near the lower end, so that the tungsten leading-out wires can be bent sharply at right angles just outside the glass wall, thus leaving a form which is flush with the diameter of the outer compartment. A glass tube 1.6 cm. outside diameter is sealed concentrically with the outside glass tube and forms the cathode leg of the cell. In addition to being sealed at the upper constricted portion of the central tube, which is about six cm. from the bottom of the cell, it is sealed at a point near the bottom and furnishes contact with the outer glass tube so that a tungsten lead can be made to connect the inner portion of the cathode without being electrically connected with the anode chamber. Just below the upper seal and about five cm. from the bottom of the cathode, a hole about one cm. in diameter serves to connect the anode chamber, which can be filled from that point. The cathode tube extends several centimeters beyond the upper joint so that after the cell is filled it can be conveniently drawn out and sealed off.

As No. 24 tungsten wire is very stiff and difficult to bend when cold without breaking, so a flexible lead was devised which prevents breaking of the wire. Just outside the tungsten leading-in wire, a tungsten-monel-copper joint was made by electro-spot welding. Such a combination holds very tenaciously and if the copper wire is redoubled back a short distance on the tungsten and wound about the joint a very flexible lead is made. The difference in temperature between the leads on either side of the cell is very small. The correction for the thermal e.m.f. is less than 2.5×10^{-7} volts per degree. The contact e.m.f. in the leads is obviously balanced one against the other as the finishing lead consists of copper wire.

The cells are mounted in a bakelite-micarta cases fitted with suitable binding posts. The top, bottom and sides of the cell proper are protected from breakage by felt pads. Although the diameter of the cell base is only about two inches, the cell is very stable, since the center of gravity is low due to the mercury near the bottom. Figs. 3 and 4 show by comparison the composition of the new form of cell. Due to the low thermal conductivity of the walls of the container and the high thermal conductivity and intimate contact of the two legs of the cell proper, external changes of temperature should have little effect on the e.m.f. of the unsaturated cell.

CELL INGREDIENTS*

Chemically pure mercury, as obtained on the market, usually contains many other metals and must be specially purified before being used in standard cells. This is done by simultaneous, continuous acid washings and electrolysis, the refined mercury being finally distilled in a vacuum still.

The mercurous sulphate is prepared from the refined mercury by the electrolytic method.

The paste is made from the mercurous sulphate by mixing it with about ten percent by volume of about 15 mesh $3\ CdSO_4\ 8\ H_2O$ crystals and making it of the consistency of thick cream by the addition of saturated $CdSO_4$ solution.

The cadmium obtained from the manufacturer is redistilled in a hard glass vacuum still, the resultant product being very pure.

The amalgam, consisting of 12.5 percent by weight of cadmium, is made by dissolving the purified cadmium in mercury at a temperature slightly above 100 degrees C.

FIG. 4—COMPOSITION OF THE H TYPE AND THE NEW STANDARD CELLS

The cadmium sulphate, as received from the manufacturers, containes small amounts of iron, nickel, zinc and traces of other impurities, so that it is necessary to resort to further purification of this material also.

*A complete description of the apparatus and methods used in purifying the materials used in these standard cells, together with a complete bibliography, is given in a paper by the authors before the American Electrochemical Society, September 30, 1920, upon which this article is based.

FILLING THE CELL

As has been stated in the description of the cell blank, Fig. 2, the central chamber is made the cathode while the outer concentric tube is made the anode. The cadmium amalgam is introduced through the circular opening near the top of the cathode tube by means of a smaller glass tube which is curved so that all the amalgam enters the chamber. A depth of 1.5 cm. is sufficient to cover the tungsten lead. The spherical part of the leg of the cathode chamber is filled slightly more than half full with mercury. The paste, as described above, is carefully pipetted into the cathode chamber so that it covers the mercury to a depth of about 2 cm. Two methods are used to hold the mercury and paste in position. The first method, which has been used heretofore, consists in thrusting a silk-covered hollow cork ring down upon the surface of the paste. The opening through the hollow cork is about 0.5 cm. in diameter. To insure the plug from chemically affecting the e.m.f. of the cell, it is first thoroughly boiled in water, dried free from moisture and allowed to soak several days in saturated cadmium sulphate solution. Acid treated silk which has been thoroughly washed and dried exists in a stable condition in contact with the cell ingredients. The alternate method of holding the paste and mercury in position consists in using a clean coil (two turns) of No. 28 tungsten wire, which is slightly larger than the cathode tube, to replace the cork. A slight annular concave depression made in the cathode tube when constructing the blank serves to hold the silk and coil in the proper position.

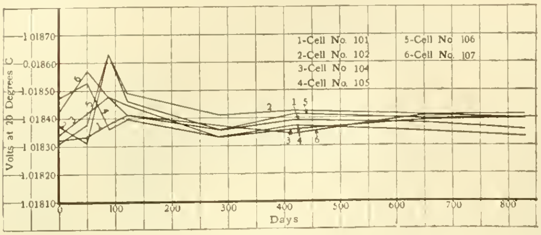

FIG. 5—SERIES OF VOLTAGE TESTS OF A SET OF SATURATED H-TYPE STANDARD CELLS

The cell is next filled to the upper seal with the saturated cadmium sulphate solution in which a few crystals of clear $3CdSO_4$ $8H_2O$ have been added. By placing the cell in cold water to a depth of 6.5 cm. a smooth seal is made by judiciously softening the hard glass with the heat of the oxygen-natural gas flame.

ELECTRICAL TESTS

After completion, these cells ware tested periodically with a potentiometer to determine the constancy of the e.m.f. Six portable unsaturated cells of the Weston type served as standards. Four of these cells were sent to the Bureau of Standards for check at various times and a weighted mean of the certificate values of these six cells was used in checking the new cells. The cells were not placed in an oil bath, but before checking they were kept in the standardization room for several hours and the air temperature close to the cells noted. The temperatures were accurate to at least one-half degree. Fig. 5 shows a series of tests covering a period of 2.5 years for an early set of saturated H-type cells made up of hard glass and tungsten leads. These cells show a smaller variation of e.m.f. than do the individual portable cells used for standardizing them. Table I gives a record of the e.m.f. of a set of unsaturated cells of the concentric type. These have not been kept for a long enough period to give useful data on their constancy.

FACTORS AFFECTING THE STABILITY OF STANDARD CELLS

Such changes noted at the mercury surface as the hydrolysis and formation of basic salt in the solution give an increase of e.m.f. as the mercury concentrates. Crystalline basic salts stop increase of free acid formation due to hydrolysis, which has a tendency to lower the e.m.f. The e.m.f. is also decreased by evaporation of the liquid, by the change in the crystalline state of the cadmium sulphate and by the inequality of the grain sizes of the mercurous sulphate. It is obvious that the cell blanks must be absolutely clean and the chemicals used must be of excellent purity. A cell which is very slightly acid makes a satisfactory working standard. A slight variation in the composition of the cadmium amalgam has no harmful effect upon the e.m.f.

The tungsten leading into the interior of the cell legs is usually covered with a small quantity of tungstic oxide. This is reduced electrolytically in dilute H_2SO_4 at the cathode, which leaves a very thin layer of spongy tungsten about the wire. Mercury is deposited upon the tungsten immediately by adding a small quantity of mercurous nitrate to the electrolyte. It is probable that a slight amalgamation of the tungsten is produced in this case. On emptying the electrolyte from the blank and after subsequent washings with distilled water, the tungsten leads remain bright due to the electrolytically deposited mercury. This process of amalgamation of

TABLE I—E. M. F. OF CONCENTRIC CELLS

Cell	E. M. F
000	1.01822
001	1.01821
002	1.01824
003	1.01813
004	1.01821
007	1.01810
008	1.01815
009	1.01811
010	1.01814
911	1.01824

the leads gives a very stable contact with the cell and is free from the high resistance effects which accompany untreated electrodes.

ADVANTAGES OF THE PORTABLE CELL

The portable cell as described has at least five distinct advantages:—

1—Compactness.

2—The cathode is centrally located, holding the mercury in a central chamber.

3—Stability of construction.

4 Legs are kept at the same temperature, thus reducing E. M. F. variations.

5 Constant electromotive force is obtained over long periods of time.

High-Speed Circuit Breakers

Air-Break Type

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Supply Engineering Dept.,
Westinghouse Electric & Mfg. Company

ROTARY converters and motor generator sets, when applied to railway or similar heavy duty service, are frequently called upon to carry sudden and heavy overloads or short-circuits which, unless suitable protection is provided, play havoc with the commutating parts of the machines. Various methods of obtaining such protection have been devised, the most recent of which is the high-speed circuit breaker.

It is the function of the high-speed circuit breaker shown in Fig. 1, to open an electric circuit after a short-circuit occurs, so quickly, that the current will be unable to reach a dangerously high value. To the eye the ordinary carbon circuit breaker opens a short-circuit with great rapidity, yet the current is able to reach the maximum value before the circuit breaker starts to open. Oscillograms show that the current on short-circuit, starting from zero value, builds up at the rate of from one million to three million amperes per second, depending upon the constants of the circuit. This means that a value of 10 000 amperes would be reached in from 0.01 to 0.003 seconds.

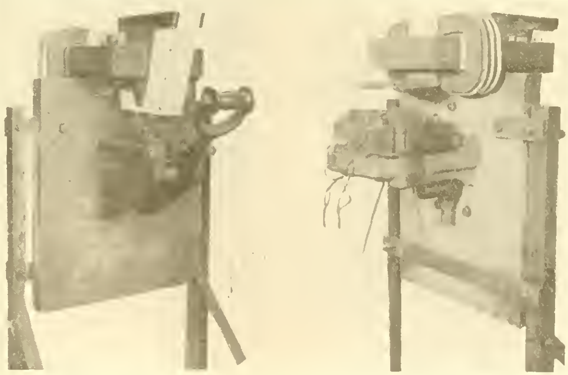

FIG. 1 FRONT AND REAR VIEW OF HIGH-SPEED CIRCUIT BREAKER

Fig. 4 represents the action of a carbon circuit breaker, which is automatic on overload, while opening a dead short-circuit on a 500 kw, 60 cycle, 600 volt rotary converter. The current attained a value of about 25 000 amperes before the circuit breaker started to open. The circuit was opened completely in 0.075 seconds and an arc was started between the circuit breaker carbons in approximately 0.05 second from the instant of short circuit. These figures represent very short intervals of time, yet an examination of this oscillogram will show that the current reached its maximum value in 0.03 second, and hence that, in order to limit the short-circuit current to a value considerably below 12 000 or 15 000 amperes, a circuit breaker would be required which operated more than ten times as fast as the carbon circuit breaker.

To design such a circuit breaker, for 750 volt, 1200 ampere service, for example, which will be simple, compact and rugged is not a simple problem. In order to obtain the extremely high speed necessary, powerful springs are required to give the proper acceleration. All of the parts which move when the circuit breaker opens must be light, and at the same time must be strong enough to withstand the slamming action of the springs. The method of holding the circuit breaker closed against these heavy springs is of great importance, since the method of tripping the circuit breaker depends primarily upon the method of holding and the speed of opening depends to a great extent on the scheme of tripping.

The construction of the circuit breaker which solves this problem is shown in Figs. 1 and 2. The upper contact of copper leaves, clamped together, is indicated by g. It is connected electrically with the series coil D. The lower contact g', similarly constructed, is connected to the stud for main line lead. A copper member b, hinged at the point h, is provided with an auxiliary copper contact or arcing tip a' at its upper end, which serves to make or break the connection between the contacts g and g'. When the handle C is pushed downward by hand, the toggle lever t forces the copper bridging member b against the powerful springs S; and thus g and g' are electrically connected. The electromagnet

M, by pulling upon the iron structure *N*, holds the circuit breaker in the closed position until it is tripped electrically.

The magnetic blow-out device, which serves to blow out the arc formed by the arc tips *a* and *a′* when

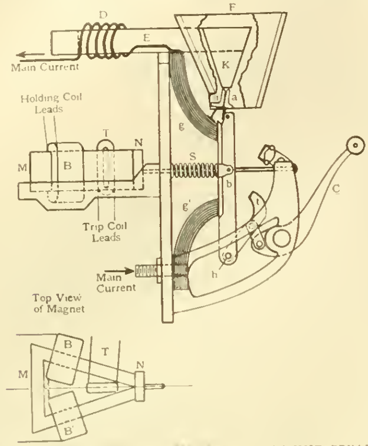

FIG. 2—CONSTRUCTION OF HIGH-SPEED CIRCUIT BREAKER

the circuit breaker opens, consists of a magnetic circuit *E*, a series coil *D* and an arc chute *F*. The coil *D*, which is connected in series with the line, produces a magnetic flux, which passes through the iron *E*, and between the pole pieces *K* which extended downward to the sides of the arcing tips *a* and *a′*. The strong magnetic field exerts an upward force on the arc formed between the tips *a* and *a′*, blowing it out through the vent of the chute *F*.

A diagram of the electrical connections is shown in Fig. 3. The coils *B* and *B′*, connected to a suitable source of direct-current, energize the holding magnet

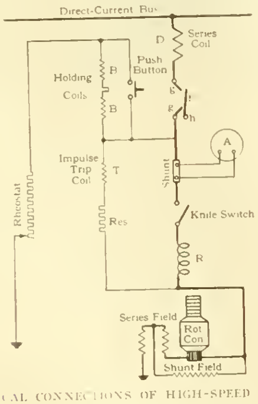

FIG. 3—ELECTRICAL CONNECTIONS OF HIGH-SPEED CIRCUIT BREAKER

M. The trip coil *T* is connected across the line reactor *R* and, in the event of a short-circuit in the line, receives a heavy rush of current due to the high voltage drop across the reactor. This current through the trip coil creates a magnetomotive-force, which shunts most of the flux away from the armature *N*, thereby allowing the compressed springs to open the circuit breaker. The time consumed from the instant of short-circuit until the armature *N* starts to move is about 0.001 second.

It is evident that this method of holding the circuit breaker closed and of tripping it, is very simple and efficient. There are no latches and levers to fail or wear out, and the speed of operation is much faster than one could ever hope to obtain with a system of triggers.

The operation of this circuit breaker in an actual circuit is represented by the oscillogram in Fig. 5. A 500 kw, 60 cycle rotary converter was short-circuited through 0.15 millihenries reactance. It is plain that the line current was unable to reach the maximum value, given in Fig. 4, which represents a short-circuit on the same machine with the same circuit characteristics. In the oscillogram shown in Fig. 5, the current was limited to a little less than 6000 amperes, which is less than one-third of the value which it would have attained had a plain carbon circuit breaker been used in place of

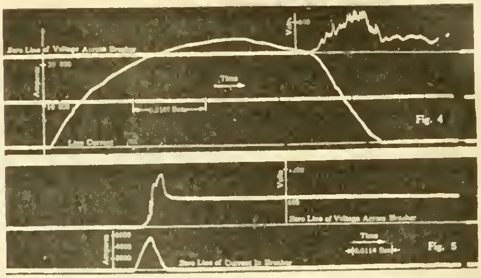

FIG. 4—ACTION OF A CARBON CIRCUIT BREAKER

FIG. 5—ACTION OF THE HIGH-SPEED CIRCUIT BREAKER

the high-speed circuit breaker. As a result the flashing on the commutator was eliminated.

The current in the line was limited in about 0.0044 second and the circuit was broken completely in approximately 0.0084 second. To obtain an idea of how fast this is, consider the peripheral speed of the commutator of a rotary converter. Assuming that there are six brush arms and that the commutator is revolving at the rate of 1200 r.p.m., it would take a commutator bar about 0.0083 second to pass from one brush arm to the next.

High-speed circuit breakers of the type described above should prove very useful in protecting the feeder circuits of direct-current machinery. At the present time, in most trolley systems, costly feeder cables are run out a mile or more from the sub-station, so as to insure a sufficient amount of current limiting resistance and reactance in the circuit when a short circuit occurs on the system. Costly and inefficient resistors are sometimes used. All of these can be eliminated by means of high-speed circuit breakers and therefore a considerable investment can be saved by their use.

Portable Electrical Equipment

For Motion Picture Photography

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Westinghouse Electric & Mfg. Company

THE PRODUCTION of nearly every photoplay involves a certain amount of outdoor photography in order to obtain a clear and complete photographic interpretation of the story. To witness a picture lacking in the important outdoor action is analagous to reading a narrative void of description and one in which many of the important incidents comprising the story are not related. The extent to which outdoor photography enters into the production of the picture, depends upon the nature of the play and also the care exercised by the producers to secure a photoplay showing a sequence of events, including all the outdoor happenings, which contribute to a clear interpretation of the story. Outdoor scenes must be taken either in the daytime or at night, and at points where the surroundings are in harmony with that particular part of the story to be photographed. Quite frequently, in order to secure the proper "setting", this work must be done at places considerably distant from the studio. In studio vernacular, outdoor photography is called "location work".

During the past, location work has been very costly. Excessive delays were frequently encountered, due to lack of sufficient daylight, which made it necessary to keep the players and equipment "on location" until proper lighting conditions prevailed. Furthermore, this work often extended over a period of several days and the variation in the photographic value of day light, occasionally necessitated a repetition of the work. This meant a delay and consequenttly additional expense, which was not conducive to economy in producing the picture.

The high cost of location work was a matter of much concern to motion picture producers and lead to the almost universal use of artificial light with daylight, as a solution to the existing problem of greater economy in the production of outdoor pictures. Artificial illumination in connection with daylight not only gives far better results than daylight alone but it also permits the location work to proceed regardless of natural light conditions, thus eliminating delays and unnecessary expense. Wonderful effects are secured by using artificial light for photographing night scenes, which previously were taken in daylight making it necessary to tint the films to obtain the night effect. The past year is significant in the history of motion pictures in that it marks a general recognition of the relative importance of artificial illumination in outdoor photography and the development of satisfactory equipment for this service.

On account of greater economy and better photographic results, direct current is vastly superior to alternating current for motion picture work. Since direct current at 115 volts is seldom, if ever, available at points where required, either portable converting or complete generating equipment is necessary to secure direct current for operating the lamps. In the vicinity of Los Angeles, portable motor-generators are used extensively, as alternating current usually is available. In localities where no electric power is available, a complete portable power plant is required. The direct current produced is used in photographing either day or night scenes, and when occasion demands, for operating small motor-driven devices.

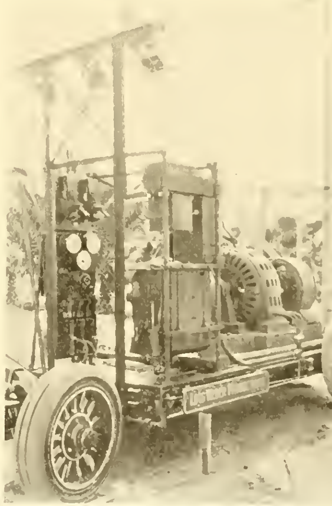


FIG. 1—LOIS WEBER PORTABLE MOTOR-GENERATOR SET FOR LOCATION WORK

Showing the direct-current generator panel on the left, and the alternating current control equipment consisting of an auto starter and 2200 volt oil circuit breaker, the transformers, and the integrating watthour meter

The equipment shown in Fig. 1, is owned by the Lois Weber Productions Company, Los Angeles, and consists of a 100 kilowatt three-unit induction motor-generator with switchboard and accessories, all mounted on a chassis.

The portable power plant, shown in Figs. 2 and 3 was designed by Mr. Otto Sarvas, electrical engineer, of the Auto-electric Devices Corporation, New York City, and used by the Sunlight Arc Corporation, New York City. This equipment consists of a 50 kilowatt, 125 volt, 900 r.p.m. compound wound generator,

mounted on a common base with and directly connected through a flexible coupling to a 150 hp, six-cylinder, water-cooled gasoline engine. The generator has stable operating characteristics and ability to carry the heavy momentary overloads so frequently encountered in mo-

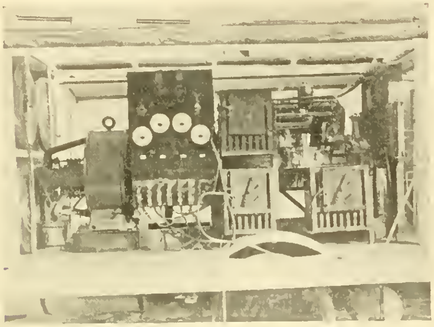


FIG. 2—50 KW PORTABLE POWER PLANT

tion picture service. This particular generator, normally rated at 400 amperes, has actually carried 780 amperes for 18 minutes. During this time, it was supplying current to three large Sunlight arcs, one 30 hp motor and two spotlight arcs. This incident occurred while the equipment was being used by the Fox Film Company, of New York, for location work.

The engine has several distinctive features which make it especially adapted to this service. It is of the water-cooled type, equipped with an exceptionally large fan and radiator. An impulse coupling on the magneto provides a very quick start. The coupling connecting the generator and engine is of the leather disc type and is welded to the flywheel. The governor is exceptionally sensitive and is adjusted so as to slightly increase the engine speed with increase in load, thereby, aiding the generator in maintaining a constant voltage at all times, which is an essential requirement for motion picture service.

FIG. 3—COMPLETE DIRECT-CURRENT GENERATING EQUIPMENT AND SUNLIGHT ARC REFLECTOR

Special attention was given to the design of the bedplate. In order to keep the total weight of the set a minimum, and at the same time provide good mechanical construction, the bedplate was built up of steel channels and angles. All joints were welded instead of bolted. This construction possesses the rigidity of cast iron and yet it is considerably lighter in weight.

The switchboard for the control of the generator and feeder circuits is securely and rigidly fastened to the steel bedplate. This equipment consists of two 400 ampere circuit breakers, three 200 ampere fused knife switches, three ammeters for the three feeder circuits, a voltmter, and a knife switch for an incandescent lighting circuit. The three large rheostats, conveniently located at the side of the engine, regulate the current for the Sunlight arcs and serve as ballasts for any fluctuations in the current caused by varying resistance in the arc circuits.

The description given above covers a complete power plant, which is mounted on a large automobile chassis provided with a specially-designed body. The truck carries a reel with one thousand feet of flexible cable, so that the arcs can be operated at a considerable distance from the power plant. Although this portable set was designed especially for outdoor motion picture

FIGS. 4 AND 5—100 000 CANDLE-POWER SUNLIGHT ARCS FACILITATING RESCUE WORK AT NIGHT

service, there will doubtless be extensive uses of this equipment for other applications, as the following incident will illustrate.

On December 1st, 1920, a large apartment house, located at 52nd Street and Broadway, New York City, suddenly collapsed, burying several persons underneath its ruins. This happened at 5:00 o'clock in the afternoon. On account of the lack of daylight, the rescue work proceeded slowly at first and with great hazard to the workmen. The Fire and Police Departments responded to the emergency call, but were unable to work to advantage, due to the growing darkness and possible danger from falling girders and walls. Within an hour after the accident was reported, the Sunlight Arc Company had their portable generating set with two 100 000 candle-power Sunlight arcs on the scene of action. One lamp was stationed on a truck at 52nd Street and Broadway. The immense beam of white light from this lamp illuminated the ruins on the Broad-

way side and part of the adjacent buildings toward 53rd Street. The other lamp was located near 52nd Street and 7th Avenue and illuminated the side of the ruins facing 52nd Street. This light not only greatly facilitated the rescue work, but further made it possible for the camera men to secure pictures from time to time during the course of the night, as shown in Figs. 4 and 5. The chiefs of the New York Police and Fire Departments were outspoken in their praises of this apparatus and the great service it can render as manifested on this occasion.

THE JOURNAL QUESTION BOX

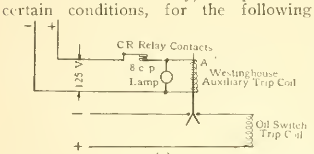
Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

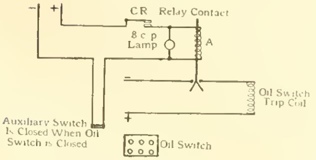
1962—PITTING OF RELAY CONTACTS—Will the connections shown in Fig. (a) prove satisfactory; that is, will the *CR* relay contacts interrupt the current flowing through the auxiliary trip coil *A* and the eight candle-power lamps without excessive burning or pitting? Or must the connections shown in Fig. (b) be used, in which an auxiliary switch, which is opened when the oil switch opens, interrupts the current flowing through the auxiliary trip coil and lamps. It is realized that the auxiliary switch can be adjusted so as to interrupt the current, thus relieving the *CR* relay contacts of this duty, but is the addition of an auxiliary switch and the required wiring necessary?

R.B.G. (MONT.)

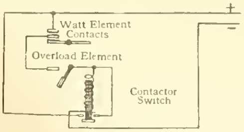
The connections shown in Fig. (a) will not be satisfactory, except under certain conditions, for the following



(a)



(b)



(c)

FIGS. 1962 (a), (b) and (c)

reason. All *CR* reverse power relays are equipped with an auxiliary contactor, which comes into action when the trip current exceeds a value of approximately two amperes. This contactor shunts the main relay contacts and is so arranged that when it is once closed it will remain closed until the trip circuit is broken by external means such as a pallet switch on the circuit breaker. A diagram of this connection is shown in Fig. (c). Therefore, if the current is equal to or above two amperes and if a standard relay is used, it will be necessary to make trip connections as shown in Fig. (b) or the trip circuit will not be broken. The value of the current taken in this case is not given, though it is probably not as much as two amperes. Hence, the contactor will not come into action and it will be necessary to use a pallet switch to prevent the relay contacts from breaking the trip circuit. The relay contacts will safely close this current but repeated breaking will cause damage from burning. The only case in which it would be safe to use this relay without an auxiliary or pallet switch is in the case of the transfer relay or direct-trip attachment, where the only current the contacts have to handle is that due to the transformer action in the teaser coil.

E.A.H.

1963—INSULATION RESISTANCE—Can you give me the resistances in ohms or megohms to ground required in manufacturing electric motors for the following voltages: 110, 220, 440, 2200 volts? What is the lowest resistance permissible for a rewound motor?

G.K. (ALBERTA)

The standardization rules of the A. I. E. E. state that "The insulation resistance of a machine at its operating temperature shall not be less than that given by the following formula:

$$\textit{Insulation resistance in megohms} = \frac{\textit{Voltage at terminals}}{\textit{Rated capacity in kv-a} + 1000}$$

From this formula the insulation resistance for motors up to 100 hp should be not less than—

0.10 to 0.11 megohms for 110 volts
0.20 to 0.22 megohms for 220 volts
0.40 to 0.44 megohms for 440 volts
2.0 to 2.2 megohms for 2200 volts

However, the insulation resistance is extremely variable. Different temperatures and different degrees of dryness as well as the dirt or dust that has settled on the windings affect the insulation resistance greatly. Induction motor stators for 110 to 2200 volts up to 100 hp will usually have about 100 megohms insulation resistance when new and dry. If the windings are not dry they may measure less than one megohm but by thoroughly drying they usually reach the above figure. Direct-current armatures on account of the creepage surface of the commutators, usually have from 1 to 5 megohms insulation resistance when new and dry.

J.L.R

1964—DIVERSITY FACTOR—Would you kindly explain how to obtain the diversity factor of any one piece of equipment, for instance that of a mine hoist, and also the diversity factor of several pieces of equipment collectively, for instance air compressor, haulage, hoist, pumping and lighting loads. Give an example of both cases.

A.W. (MINN.)

The expression "diversity factor" is never used in connection with a single piece of power equipment or small group of equipments in one location. For a condition of this kind, the expression "load factor" is more generally applied. Load factor may be defined as the ratio between the average load and the full capacity of the equipment. The average load is obtained by means of a watthour meter, or by integrating a graphic power curve. The load factor may be hourly, daily, weekly, monthly or yearly. Diversity factor is used in connection with several groups of equipment which may be operated at separated points, but supplied from the same source of power. It is the ratio of the combined peak loads (momentary or integrated time peaks) to the total sum of the individual peak loads. Where the various groups of equipment are of the same nature, the diversity factor is not very great. Where the type of load for the various groups is entirely different the diversity factor may be quite high. A high diversity factor enables a central station to take care of a number of groups of apparatus that would require isolated plants of a much greater combined capacity. The method of obtaining the diversity factor is to take the load curves, either estimated or from graphic meters, of the various groups of apparatus and combine these curves to obtain a total power curve. The diversity factor is obtained by determining the peak load from the combined curve and taking the ratio of the summation of the separate peaks from each group of apparatus to this combined peak. For an example, to illustrate load factor, let us assume that a power plant has a capacity of 1000 kw. The total output in kw-hours per day is 15,000. The

daily load factor would therefore be 15 000 divided by 24 000 or 0.625, or 62.5 percent. As an example of diversity factor, assume the same plant is furnishing power to four groups of apparatus: a mine, a quarry, a street railway and a pumping station. The 15-minute integrated time peak is 350 for the mine, 350 for the quarry, 400 for the railway and 300 for the pumping station. The total sum of the individual groups would give a peak load of 1400 kw. However, due to the fact that the peaks come at different times, the total combined peak would be about 1000 kw. The diversity factor is, therefore, 1.4 to 1. G.B.

1965 — Synchronous Converters — What phenomenon takes place in a transmission line that causes synchronous converters suddenly to reverse their direction of rotation? This peculiar change takes place either during or immediately following the interruption of the supply circuit by the tripping out of a main oil switch some where in the system. The above condition is always preceded by a surge or kick. Reversing of the rotation of the armatures has taken place in five substations at one time or another, although infrequently. Four substations have two converters each while the other has but one. Whatever occurs affects only one machine at a time. After the converter stops and is again connected to the source of supply it starts off in the right direction as though nothing had happened. Another peculiar thing that has come under our observation is the over speeding of the armature immediately after a surge. In this case the power is not interrupted. The transmission line is part of a large power system at 60 000 volts. O.D.G. (N. Y.)

If a converter flashes over during a line disturbance, this flash short-circuits all the commutator bars and the short-circuit armature currents set up an armature reaction in the same manner as in a polyphase armature winding when it is short-circuited. This armature reaction is momentarily of very heavy strength and is directly demagnetizing in its reaction on the main field pole flux. In some converters the armature reaction may greatly reduce or even entirely reverse the polarity of the main field flux during a flash over and cause either an overspeed or temporary rotation in reverse direction. A partial flash over may cause overspeed without the rotary converter permanently falling out of step, while in case of reversed rotation, the rotary converter always finally stops. F.T.H.

1966 — Reversed Current in Ammeter—Following a short-circuit in the pilot lamp of an exciter supplying a synchronous motor, I find that the ammeter is reversed. How do you account for this reversed current? How can the ammeter be made to register without changing its leads? M.B.E. (ORE.)

Without more information in regard to the type of exciter and the troubles experienced, we cannot definitely account for the reversed current. If the exciter were a non-commutating pole machine, with the brushes shifted forward for commutating purposes, a short-circuit on the exciter leads would cause such a heavy current to flow in the armature circuit, that the armature reaction, which is in such a direction as to oppose the main field flux, might overcome the main field flux and thus change the polarity of the generator. This would, of course, cause the ammeter to read in the reverse direction. If the leads are to be unchanged, the ammeter can only be made to register correctly by reversing the polarity of the generator, so that its polarity will be the same as it was originally. To do this, impress a separate source of direct current for a few seconds upon the shunt field circuit in a direction opposite to that in which the current is now flowing. This will reverse the residual magnetism of the fields and cause the exciter to build up in a direction such that the ammeter will read correctly. Also if the exciter were short-circuited again its polarity would be reversed, but we do not recommend that this be done. C.L.

1967—Choke Coil Effect of Armoured Cable—Will the armour of a three-conductor lead covered armour protected cable act as a choke coil for lightning protection? R.H.L. (B.C.)

Any cable with a grounded sheath receives considerable protection from lightning by the condenser effect of the lead sheath. This gives just the opposite effect to that caused by the inductance of apparatus windings. The latter piles up the voltage of a steep wave front or high frequency surge and increases the likelihood of insulation failure, while in the case of the cable the condenser effect of the sheath tends to bypass the surge to ground and reduce its voltage and steepness. It makes little difference, however, what the material of the sheath may be, as the magnetic effect of an iron sheath is very small to steep wave front surges. Q.A.B.

1968—Twin Motor Drive—In small direct current hoists up to two hundred horse-power if the increased first cost was cancelled by immunity from total break-down, does not a twin drive adapt itself better than the single larger motor. I have in mind, particularly, the electrifying of steam geared hoists. The single motor with its large pinion, is not always easy to arrange symmetrically with the counter shaft, while the equivalent pair of smaller motors usually can be. J.G.B. (CAL.)

"Twin drive" is rather misleading; "two motor drive" is better. Twin drive would apply to the twin motors as used in the Chicago, Milwaukee & St. Paul locomotives. The use of two motors instead of a single motor is frequently desirable on hoist drives. It is not possible, however, to say that all small direct current hoists up to 200 hp would be better driven by two motors instead of one if it were not for first cost, as there are a great many applications where the use of two motors would only complicate the installation without gaining any advantage. Under the following conditions the two motor drive will be preferable to the single motor and as a general proposition will justify the increased cost of motor and control equipment. The following applies regardless of the size of the equipment:

a—Where the mechanical arrangement on the hoist is such that in a change of motive power less changes will be necessary.

b—Where physical limitations due to transportation problems, accessibility, or space available for installation make it necessary to reduce the size and weight of the individual parts to a minimum.

c—Where it will be possible to operate at reduced capacity with one unit in case of accident to the other. (This will not always be the case, as in a great many hoisting installations, particularly with unbalanced operation and with balance operation in very deep shafts, one motor will not have sufficient torque to handle the empty cage or skip.)

d—Where it is desirable to use series parallel control in order to cut down power peaks in starting and in the handling of exceptionally heavy loads at reduced speeds. (This applies only to direct-current hoists, while *a*, *b* and *c* apply equally to alternating-current hoists).

e—Where it is desirable that the inertia of the moving parts be kept to a minimum to permit of rapid acceleration. The inertia of the revolving parts of two small motors will generally be less than that of the equivalent larger motor.

In the study of an actual problem several of the above factors may be present, in which case the two motor arrangement would doubtless be selected but unless some outweighing advantage is gained it is generally preferable to stick to the simpler single motor drive. R.W.M.

1969—Heating of Iron in Alternator—Recently, being called on a trouble job on a 110 kw alternator, with a five kw exciter I found that the iron of the alternator got hot and I assumed this to be oversaturation of the iron. The exciter also got very hot having a temperature rise of 40 degrees C. after one hour's run with the load on the alternator. We could not find any cause for the heating of the exciter, everything seemed to be right, still the exciter got very hot. The power-factor of the alternator was 80 per cent. We did not have a rheostat in series with the field coils on the rotor. I assumed that if we had a rheostat for the alternator field coils we could regulate the generator voltage and reduce the load. Will you kindly let me know if my assumption is correct, if not, kindly give your views on the subject. W.S. (N. J.)

The only effect of an alternator rheostat would be to raise the exciter voltage and possibly increase its temperature, assuming that the alternator is operating alone. It would have no effect on the alternator unless the alternator is operating in parallel with other machines and the exciter voltage is now higher than it should be. In that event the armature and field currents of the alternator and voltage of the exciter could be reduced by adding an alternator rheostat. D.H.

1970—GROUNDING OF STATOR COILS—I am having trouble with a 75 hp, three-phase, 60-cycle, 440 volt, 720 r.p.m. slip ring motor. I have wound this motor and have taken unusual precautions in winding it. With all the precautions this motor breaks down to ground at times. It has a voltage test to ground of 2200 volts. The other day one of the coils grounded in spite of the fact that it has been in service not over three months. It received the usual insulating paint, and in addition I put on a heavy coat of weather-proof varnish. It has a good clearance between rotor and stator, does not pull any over load, its running load is 45 to 55 amperes per phase. The motor is used in a glass manufacturing plant to rotate a mammoth drum on gear wheels with a chain drive. The gear wheels revolve this drum, which weighs from 55 to 65 tons. The drum contains liquid glass. The condition under which it works is this. As this drum revolves it carries the liquid glass up the sides of the drum, and when the contents let go it carries the drum forward faster than the torque of the motor revolves it. Of course this is on only one spot of the revolution. There is also a large amount of vibration, due, of course, to the liquid glass slipping off the sides of the drum. The secondary resistance is O. K. and there are no open leads. The voltage is good, being 460 at one board from 2300 volt primary. Am I correct in assuming that the carrying forward of the rotor faster at times by the drum than the torque would revolve it, has a tendency to puncture the insulation? This last ground I have not examined because I cut out this coil in order that we might continue operation. But previous to this the coils showed a clear burn off of the insulation of three coils at the diamond turns or rather half way between the end turn and the laminations. The conductors are of standard square wire used for 75 hp motors. The motor is protected by a circuit breaker which is equipped with no voltage and under voltage trip coils, and it works properly. G.G. (N.J.)

We see nothing in the nature of the torque conditions that should cause the motor to break down, but the information given would indicate that the trouble is due to the vibration of the motor. We would suggest that a flexible coupling be placed between the motor and the gear of a type that will effectively eliminate the shock and vibration which presumably is now imposed upon the motor. Overspeed might cause mechanical chafing of the insulation on the rotor. S.A.S.

1971—ELECTROLYTE FOR CHEMICAL RECTIFIER—If you know any solution that can be used as an electrolyte for a rectifier, kindly let me know. I have found ammonium phosphate pretty good, but I would like to get something still better. It must not attack iron, as I want to use it in an iron jar. I thought that the solution used in the lightning arrester described in the June issue of the JOURNAL might do the trick. T.M.S. (CAL.)

We suggest that ammonium citrate be used with about 25 grams of ammonium citrate per litre of distilled water. If you desire to use electrolyte such as used in electrolytic arresters, you should order this from the manufacturers. However, you will find that the ammonium citrate and ammonium phosphate solutions will give you far better results than the electrolyte used with electrolytic lightning arresters. G.C.D.

1972—UNSTABLE SPEED OF DIRECT-CURRENT MOTOR—We have several five hp, 220-volt, 400 to 1800 r.p.m. direct-current adjustable speed motors equipped with reverse controller. The motors have commutating poles, shunt coils and compensating coils in slots in the face of main poles. The motors operate properly in both directions up to a point about three field steps from the last point. They operate O. K., running clockwise on the last point, having two 40 watt 220 volt lamps in series with field resistance. In the counter clockwise direction the speed of the motor is stable while running on the third point from last; but when advanced to the next point the speed will rise and fall, causing bad sparking across the brushes. The surging gradually becomes of longer periods with increased sparking. The brushes were on the fixed factory position, and shifting them did not help to improve the conditions any. The motor was tried with compensating coils cut out, with commutating poles reversed, with armature reversed and with compensating coils reversed; but no improvement resulted. We had no meters to take readings by running the motor as a generator. Would you please advise me how to get these motors to operate properly. J.E.M. (MICH.)

All imperfectly compensated direct-current shunt motors have a tendency toward instability. This tendency is partially or entirely neutralized by the effect of the resistance drop in the motor. If not entirely neutralized, to make the motor perfectly stable it is necessary to shift the brushes from mechanical neutral forward in the direction of rotation, or else to put an additive series winding on the fields. If this effect is secured by brush shift it does good in one direction of rotation only and makes the motor more unstable in the other direction. Small compensated motors are usually very imperfectly compensated. In this case, from the fact that sparking occurred, and that the motor was unstable for one direction of operation only, it seems that the brushes were shifted off neutral to get stability. Put the brushes on neutral. To do this run the motor in each direction of rotation at the same load, with the same shunt field amperes, and at the highest speed at which it is stable, and shift the brushes till the speeds under these conditions are practically the same in both directions. Then see if, with this brush position the motor is stable over the full speed range and in both directions of rotation. If this has not corrected the trouble it will be necessary to put a few series turns on each of the main poles. These series turns should be connected additive and in such a way that, when the direction of current through the armature is reversed at the reversal of rotation, the direction of current through the series field is unchanged. M.S.H.

1973—EXPLORING COIL—I have to locate a network of underground water mains and steam pipe returns, and want to make up some kind of an inductive locator. I do not want to apply the commercial alternating current through the transformer to two sections of the pipe because I will get a sound in the exploring coil whenever I am near a transmission line and this method will not help me in locating the pipe. Can you tell me about the design of an exploring coil and some kind of a vibrator to operate on a storage cell to use for this work? L.A.B. (N.J.)

We presume that you have in mind passing an alternating or pulsating current through the pipes and locating them by means of an exploring coil connected to a telephone receiver. Unless your pipes are very close to the surface a considerable current will be necessary to give reliable results in your detector. An interrupter operating with large current from a storage battery would be very hard to construct unless operating at very low frequencies. However, it is possible that with low frequency the successive clicks in the telephone due to opening and closing the direct-current circuit might enable you to locate the pipes. It seems to us that a more satisfactory method would be to use a transformer giving a fairly large secondary current the primary of which is connected to a commercial supply line through a circuit breaker. If now the circuit breaker is opened and closed automatically every few seconds the field due to the testing circuit could readily be distinguished from that produced by the power lines in the vicinity. For an exploring coil use one having a large number of turns and not too small a cross section. The larger the number of turns and the greater the cross section the greater the sensibility provided the resistance is not excessive. In order to obtain the maximum inductance for a given size and length of wire the coil should have the following relative dimensions: inside radius 1; outside radius 2; axial length 0.3. T.S.

1974—CAPACITY OF AIR PUMP—What method is used in determining the volume of air passing through a centrifugal hydraulic air pump; for example, a Westinghouse—LeBlanc rotary air pump connected to a 25 000 sq. ft. surface condenser and rated at 20 cu. ft. per second at the pressure prevailing in the pump. How can the performance of this pump be checked under working conditions. P.M.J. (N.Y.)

The method normally used is that of blanking off the air suction and applying a calibrated orifice. The rating of 20 cu. ft. is that of rare air at an air pressure of approximately 0.75 in. mercury. With the air pump water having a temperature of seventy degrees, this would mean, basing the air pump on an absolute pressure in the air line of approximately 1.5 inches mercury. This would mean the use of an orifice approximately 3/8 inch diameter. G.S.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

FEBRUARY 1921

The Handling of Copper

Copper cannot be given the same rough treatment that iron or steel or brass will stand, but requires some important precautions in its handling and application. It fails quickly under localized stresses. Sharp bends, rough or nicked edges in copper straps or wires, limited movement to take care of expansion and contraction, are all points especially to be guarded against. This is particularly true when the copper is subject to quick sharp blows or vibration, such as are common with railway motors.

BENDING OF COPPER

All bends in copper should be made free and easy, that is, they should be given as large a curvature as is possible in the space available. Where sharp bends and sharp fillets are made the effects of vibration, expansion and contraction, or the throwing out forces due to rotation show up first.

Frequently sharp bends are made, at the ends of copper strap field coils, when making the clamped or soldered joints, in many cases the bad conditions that have been set up are overlooked. The sharp bend or kink may later be the cause of a motor failure which could have easily been avoided. It often happens that the armature coil failure is at a point where the wires have been carelessly bent or crossed.

NICKING OF COPPER

The nicking of copper is another kind of abusive practice to be avoided. It is very easy to nick copper with the sharp edge of a metal drift or on other tools such as are used in connection with the winding of armatures. It is preferable to use a hard fibre drift and drive leads down into commutator neck slot by using a copper filling piece placed on the lead to receive the blow from the hammer. Another source of trouble due to nicking of copper is found in field coil cable leads breaking at the point where the insulation has been cut off with a knife, the break having been started by the knife nicking the strands of the cable. Such nicks are the starting point of breaks, as surely as are those which the glazier cuts in glass when he is cutting it for the window pane. Extreme care should be used in removing insulation on all cables and wires of small cross-sections.

EXPANSION AND CONTRACTION

For the same temperature a piece of copper will expand more than a similar piece of iron or steel. Further, it is usually found that, in a motor, the copper becomes hotter than the other materials of which the motor is made. Therefore, it is necessary to provide means for the copper to expand and contract to take care of the relative motion between the different materials for the changes in temperature. A common error in this respect is to anchor wiring around the frame connections or to the frame proper when it should have been securely bound to the windings, so that it would be free to move with the windings. It is obvious that this is more important with solid strap conductors than with flexible cables.

CLEATING AND SUPPORTING

Properly supported copper stands up well against vibration. In fact, one finds it extensively used in certain applications where vibration occurs, because of its good behavior in this respect. But improperly supported, copper fails miserably under vibration. This point is frequently ignored in connecting car wiring cables to the motor leads when cleats are not applied. Care should be observed to study this point with the purpose of properly locating the cleats in supporting the cables. It often happens that the weight of a solid connector even though it may look rather small is sufficient under vibration to cause the copper strap or stranded cable to break at a point just behind the connector where stresses are localized.

TINNING STRANDED COPPER BEYOND SUPPORT

Just here also must be emphasized the bad effects of tinning stranded copper beyond the point where the joint is made. Thus, for example, instead of coming right out through the end of the connector, the solder should stop just inside the connector so that the stresses will not localize on the strands where the tinning stops and where the strands are not supported against vibration.

SICKNESS OF COPPER

Copper is subject to a form of sickness which so far as has been experienced is peculiar to copper alone. This subject has been thoroughly discussed by Mr. Piling*. All commercial copper contains a small amount of oxygen in the form of copper oxide, without which it has poor mechanical characteristics. When it is heated in a flame which is rich in free hydrogen, this hydrogen unites with oxygen forming free copper and steam. It is a peculiar characteristic that the hydrogen will readily enter the hot copper, but the steam cannot get out. The copper is thus not only weakened by the elimination of the copper oxide, but the high pressure steam expands, producing a spongy effect which still further weakens the copper. This effect is, of course, greatest near the surface. This peculiar form of sickness should be guarded against by the operating men. An experience in connection with some failures on copper, which occurred due to this change in structure, will serve to bring out this lesson.

AN EXPERIENCE IN THIS SICKNESS OF COPPER

An armature was being wound with coils having nickel silver resistance leads, with copper tips brazed onto their ends. A number of coils had been put in place when it was found that the first one had to be removed. In doing this, the copper tips were bent back to get them out of the way. With only a single bend one of the tips broke off in the workman's hands. On examining all the tips of the coils, twelve more defective ones were found. At first it was thought that it was a bad lot of copper. Tests showed that the copper, from which the tips were made, was of good quality. A study of the process of handling the copper revealed that the defective tips had been heated in a flame containing unburned hydrogen.

Since one cannot see, without breaking the strap or wire, whether the copper has been affected by the sickness, it follows, that to be safe, copper should not be heated in a flame containing an excess of hydrogen. This means that with a blow torch the copper should be kept outside of the inner cone of blue flame. When heating copper in a gas and air furnace, an excess amount of air should always be used, as too little air will produce an excess of free hydrogen. Smoke from such a furnace always indicates too little air and the mixer should be adjusted to give a little more air than is necessary to prevent any trace of smoke. Wherever possible the copper should be heated without coming into direct contact with the flame.

CLEANING INSULATION FROM COILS

It has been common practice to burn the insulation from old coils. This should not be done where the coils are to be reinsulated and used again. The question then comes; how are we going to remove the old insulation? One big operator places the coils in an oven and passes steam through the coils for 12 or 14 hours. He finds that the insulation peals off easily while hot. Another operator dips the coils in a weak solution of muriatic acid for a time (approximately 24 hours) so that the acid weakens the insulation, but not long enough to give the acid a chance to eat into the copper. The necessary time required can easily be established by checking carefully and removing the coil when the brightening of copper commences. After the acid treatment, the coils should be thoroughly washed in clear water.

SUMMARY OF PRECAUTIONS

1—Avoid sharp fillets and kinks as well as bends of small radii.
2—Do not nick copper under any condition.
3—Remember that this metal will expand and contract in service.
4—Provide proper supports against vibration.
5—Use extreme care in tinning cables.
6—Avoid heating the metal in a flame.

J. V. DOBSON

*In the Journal for August, 1920, p. 320.

The Electric Journal

Vol. XVIII — March, 1921 — No. 3

Electric Paper Machine Drive

The paper industry ranks with the greatest industries of the country; it stands sixth in the value of the annual product and in capital invested and probably fourth in primary horsepower installed. It is estimated that for 1920 there were 110 000 persons engaged in the manufacture of paper in this country. The capital invested was approximately nine hundred million dollars and the value of the product was approximately eight hundred fifty million dollars.

During the war period, it was practically impossible for the paper mills to improve their plants or expand them; practically no progress was made in the industry. As a result, the post-war boom of 1919 was encountered with mills badly in need of improvements and inadequate in number. During the last two years much has been done to improve this condition, and a great deal of interest and attention is being given to the subject of greater economies, which are made possible by further electrification of the manufacturing processes.

The most important recent improvement in this industry is the electrification of the paper machine, using sectional individual motor drive with automatically controlled speed regulation. The paper machine is the fabricating element of a paper mill and presents problems of drive which are very complex. This unit is a group of mechanically independent parts covering considerable space. A wide range in speeds is required for different kinds and grades of paper and it is necessary to operate the sections at slightly different speeds. Extremely close speed regulation is essential under all operating conditions.

For years paper manufacturers have realized the disadvantages and limitations of line shaft and rope drive and have hoped for their elimination by the development of a successful system of sectional individual motor drive. A few installations of multiple motor drive were made ten or twelve years ago, but with only partial success. It was found practically impossible to obtain the same characteristics in the different motors, and to maintain the proper speeds of the paper machine sections both personal attention and objectionable hand operation of field rheostats were required.

All line shafts, spur and bevel gears, belts and pulleys transmitting power, in fact all of the uneconomical and unreliable parts of the older forms of drive should be eliminated by sectional motor drive. To be of the greatest benefit to the paper industry, the drive should be suitable and successful for all kinds of paper machines, either high speed news machines, medium speed book or specialty machines, or slow speed board machines.

The system of sectional individual motor drive and control described by Mr. Staege in this issue of the Journal is the result of years of engineering experience and study of the problems of paper machine drive. As compared with other systems which have been devised this drive has several superior features, namely, it eliminates all of the undesirable features of the older types of drive and is equally applicable to all kinds of paper machines.

The section motors of this system may be direct connected or geared to the paper machine shafts. The method of connection is optional on medium and high-speed paper machines; on slow speed board machines, direct connected motors are impracticable. To determine the most suitable type of driving unit, each installation must be carefully analyzed from the standpoint of cost and efficiency.

The control is entirely automatic in nature, requiring no operating attention other than the usual care given to any ordinary electrical apparatus. Electrical automatic control equipment is far past the experimental stage and, because it eliminates the personal element, it is more reliable than hand operation.

An installation of this system of sectional drive and automatic control has been in operation for about a year and a half in the plant of the Gould Paper Company, Lyons Falls, New York, on a 148 inch newspaper machine. During this time no interruptions in service have been caused by the failure of the regulating equipment to function properly. The management of the mill and the machine operators have only satisfaction and commendation to express for the successful operation and the beneficial results it affords. A number of complete installations of sectional motor drive and automatic control on several different types of paper machines will be in operation in the near future.

W. H. Artz

Automatic Speed Control for Sectional Paper Machine Drive

STEPHEN A. STAEGE
General Engineer
Westinghouse Electric & Mfg. Company

PAPER is made from a pulp stock, consisting of cellulose fibers carried in suspension in water. It is transformed from this liquid mass into a smooth sheet of paper in one continuous operation on the "paper machine", which is the largest and most complex of the various pieces of apparatus used in the manufacture of paper from the raw material. While differing in size, these machines are usually several hundred feet long, weigh hundreds of tons and frequently cost several hundred thousand dollars.

The paper is formed on a wire screen upon which the pulp solution is evenly deposited. Part of the water gravitates through the wire screen, part is drawn through the screen by vacuum suction boxes and still more is removed by the passage of the semi-formed sheet between large press rolls. Finally, after most of the water has been removed in this manner, the paper sheet, now thoroughly fabricated, passes onto large revolving drying cylinders heated by steam, where nearly all of the remaining moisture is evaporated. From the drying cylinders, the sheet passes to the calendar stack where it is ironed out to a glossy hard smoothness by its passage between numerous highly polished steel rolls, stacked one above the other, around each of which the paper is threaded. After leaving the calender the paper is wound into a large roll on a reel. It is later trimmed to the desired width and rewound into new rolls of the dimensions required for the ultimate user.

Paper machines are divided into two principal types, known as Fourdrinier machines and cylinder machines. The Fourdrinier machines are used chiefly for the lighter weights and thicknesses of paper, such as news print paper, book paper, etc., and usually operate at relatively high speed, whereas the cylinder machines are used almost exclusively for heavy papers, such as card boards, container boards, box boards, etc. In the Fourdrinier machine, the sheet is formed on a wide wire screen operating like a belt around two rolls, and driven by one of them called the couch roll, the pulp stock solution being deposited evenly upon the surface of this wire screen. In the case of the cylinder machine, the liquid pulp stock is deposited upon the surface of a revolving screen drum or in many cases upon a number of these revolving screens known as cylinder moulds, each of which adds a thin layer of pulp stock to a revolving felt, making a sheet of any desired thickness. The fundamental difference between the Fourdrinier machine and the cylinder machine is that, in the Fourdrinier machine, the sheet is formed upon the screen, called the Fourdrinier wire, whereas in the cylinder machine the sheet is formed on the cylinder moulds. The presses, dryers and calenders are similar in both machines. On account of the higher speeds at which Fourdrinier machines operate, many variations in mechanical design are found in the two general types of machines.

FIG. 1—148 INCH FOURDRINIER MACHINE FOR MAKING NEWS PAPER
Equipped with individual motor drive, using Westinghouse automatic speed regulating system.

When passing between the press rolls, the thin, wet sheet is slightly elongated and in its passage between presses it is acted upon to a certain extent by the atmosphere, causing evaporation and a tendency towards shrinkage. This is also true in the passage of the sheet from the last press to the dryer rolls and through the dryer rolls to the calenders. On this account, it is necessary that the paper machine be so constructed that each of its component parts or units, that is, each of its press rolls, trains of dryer rolls and stacks of calender rolls can be operated at a slightly different speed, in order to compensate for the variations in the elongation or shrinkage of the sheet that may take place from time to time, due to changes in atmospheric

conditions or to variations in the consistency of the pulp stock as it is fed onto the machine.

From this brief description of the paper machine, it will be seen that each section must be susceptible to individual speed adjustment and control. Moreover, the correct relative speeds of each of the sections must be maintained with great precision, or the paper sheet will quickly be broken.

The speed at which paper machines operate also varies greatly. In cylinder machines, the linear speed of the paper may be only a few inches or feet per minute or it may be two or three hundred feet per minute. The machines will vary in width from those which can produce a sheet of paper 3 or 4 feet wide to those which can produce a sheet 10 or 15 feet wide. Sometimes a single machine may be required to operate over a great range of speeds, varying from perhaps 10 or 15 feet per minute to 200 feet per minute, so that whatever method of drive is used, it must be capable of operating over a considerable range of speeds. Fourdrinier paper machines seldom operate at speeds lower than 50 or 100 feet per minute. The upper limit of speed so far obtained is 1000 feet per minute. Many machines , however, are operating continuously at from 600 to 700 feet per minute.

The most common method of driving paper machines has been by means of a variable speed engine, or an adjustable-speed direct-current motor. Each of the several sections is driven from a common line shaft by reduction gears, belts and pulleys or some type of rope drive, the belts being made to operate with pulleys slightly tapered or conical in form, so that by shifting the belt toward one end of the pulley or the other, the required adjustment of speed for each individual section can be obtained.

Since the variations in load on any individual section at a given speed are not great, seldom exceeding 20 or 25 percent, the belt can be depended upon to transmit the load with a fairly constant slippage, and therefore relatively uniform speed. Following every change in load transmitted, there is, of course, a slight change in the amount of belt slippage on the pulleys, which necessarily effects to a certain extent the "draw" of the sheet between the sections, caused by the difference in relative speeds between the sections which have taken place. It is well known that variations in belt slippage are also caused by changes in the humidity of the atmosphere, effecting both the tension of the belt and the co-efficient of friction between the two surfaces, or by water, oil or foreign matter of any kind reaching the surface of the belt or pulleys. On account of the liberal rating of the belts which are commonly used, the degree of variation of belt slippage has not been sufficient to interfere seriously with operations, although it does frequently cause breakages of the paper sheet as it passes from one section of the machine to another, and more often causes undue straining of the sheet so that, while it does not actually break on the paper machine, it may break later while passing through printing presses.

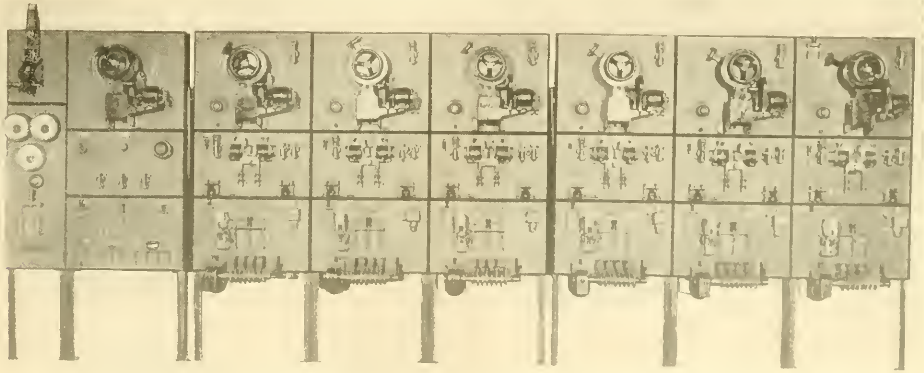


FIG. 2—CONTROL BOARD FOR SECTIONAL DRIVE 166 INCH FOURDINIER BOOK PAPER MACHINE

Heretofore, mechanical drive has been used almost exclusively for the various sections of the paper machine. The reason motors have not been used for driving the individual sections, was because no means had been found whereby their speeds could be controlled accurately enough to prevent breaking of the paper, most of the trials of sectional motor drive having resulted disastrously. From the fact that the relative speeds of the sections have to be adjusted from time to time, synchronous motors are out of the question, and induction motors, on account of their inherent regulation characteristics, are equally unsuitable. Direct-current motors, on the other hand, can be designed to operate over wide ranges of speed, and offer great flexibility of control, and the only thing that has interfered with their general adoption has been the absence of a

suitable type of speed regulator. Recent investigations have shown that, to prevent breakage or undue straining of the paper as it passes from one section to another, the variation of speeds between sections must be maintained, as an average value, within one-tenth of one percent. It is also necessary to raise or lower the speed of the entire paper machine by small amounts from time to time, without interfering in any way with the draw, or relative speeds of the various sections, and it is necessary, when changing from one grade of paper to another, to operate at widely different speeds; speed variations of 7 to 1 or even 10 to 1 frequently being encountered. Obviously, no standard regulating equipment heretofore on the market would meet these exacting requirements.

For many years, manufacturers and engineers have appreciated the great loss of power occasioned by the existing mechanical type of paper machine drives, the enormous amount of space required for the accommodation of the long line shafts, pulleys, belt drives, reduction gear units, friction clutches, etc., and the personal and fire hazard unavoidably associated with this type of transmission. Still more serious is the great loss of production resulting from the frequent paper breakages caused by excessive belt slippage and interruptions of operation for repairs to the various parts of the mechanical system, such as the friction clutches, belts and gear units.

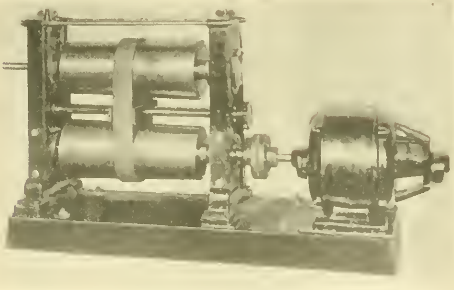


FIG. 3—SPEED CHANGER AND FREQUENCY GENERATOR

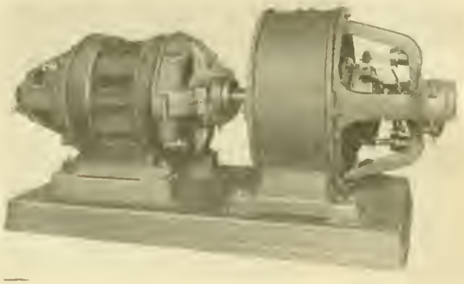


FIG. 4—MASTER FREQUENCY GENERATOR SET

These disadvantages can all be eliminated by the substitution of sectional individual motor drive, with a sufficiently sensitive scheme of controlling the motors, which would at the same time be sufficiently rugged to withstand severe and continuous operation in the hands of unskilled labor, and would be free from the necessity of adjustment or care by skilled electricians.

In response to the increasing demand for sectional motor drive, greatly accentuated by the desire to increase paper machine speeds, which are limited by the mechanical system of drive rather than the characteristics of the machine itself, a perfected type of sectional individual motor drive for paper machines with automatic regulation and control has recently been developed. This new system of sectional paper machine drive involves the development of a type of regulator not heretofore used, whereby the speed of the direct-current driving motors is maintained automatically within one-tenth of one percent; and the use of other standard control equipment for starting and stopping the motors. The regulator equipment itself does not include any delicate instruments or apparatus likely to get out of order, such as are usually associated with exceptionally sensitive regulating devices, but is fully as rugged and reliable in every respect as the most approved control apparatus used in industrial applications.

The complete system of sectional paper machine drive and control herein described consists of an adjustable voltage, direct-current generator, of sufficient capacity to drive the entire paper machine, with direct connected exciter; a direct-current adjustable-speed motor for each section of the machine; suitable means for connecting the motor to each section of the paper machine driving shaft; and a control system which automatically maintains the correct speed of each individual motor; together with push button stations for starting, stopping and adjusting the speed of the paper machine as a whole.

The generator usually forms part of a standard synchronous motor-generator set or turbine-generator unit, and is a 250 volt, adjustable-voltage, separately-excited machine with a constant voltage 250 volt exciter of sufficient capacity to furnish excitation for the synchronous motor field, the generator and motor fields, and for the control circuit of the regulator. The motors, are 250 volt, separately-excited machines, and may be of any desired speed, dependent upon the particular requirements of the paper machine involved. Where a comparatively small range of speed for the paper machine is desired, that is, not more than 3:1 or 4:1, this is accomplished by voltage control of the generator through a motor-operated field rheostat. Where very wide ranges of speed, such as 10:1 are required, both generator voltage control and motor field control are used, the same motor-operated face plate controller or rheostat serving to insert resistance in the shunt fields of the several motors uniformly, after the generator has been brought to full voltage.

The automatic control system consists of a small master frequency generator driven by a small direct-current motor operating in parallel with the section driving motors and separately excited; a small frequency generator driven from each of the section driving motors through a small speed changer consisting of two cone pulleys, to one of which the frequency generator is coupled; a powerful synchronous type of rotary relay for each driving motor, which serves to make an electrical contact in one direction or the other on the slightest unbalance of frequencies; and a motor-operated field rheostat, under control of the relay, in the shunt field circuit of each driving motor. The master frequency generator is common to all sections of the paper machine, whereas each section has their own ball bearings, which is practically negligible. By shifting the small belt on these speed changers by means of a hand wheel, the relative speeds of the sections, or the draw of the paper, as it is called, is accurately and positively determined by the operator, and is thereafter maintained automatically at the correct value. Any unbalancing of the two frequencies at the rotary relay, caused by change in speed of the driving motor, immediately causes a positive synchronous movement of the relay, making an immediate contact and thereby adjusting the field strength of the motor, and returning the speed to the required value.

Before any governor or regulator can function, there must be a change of some kind, in either load or speed, as otherwise there would be no occasion for the

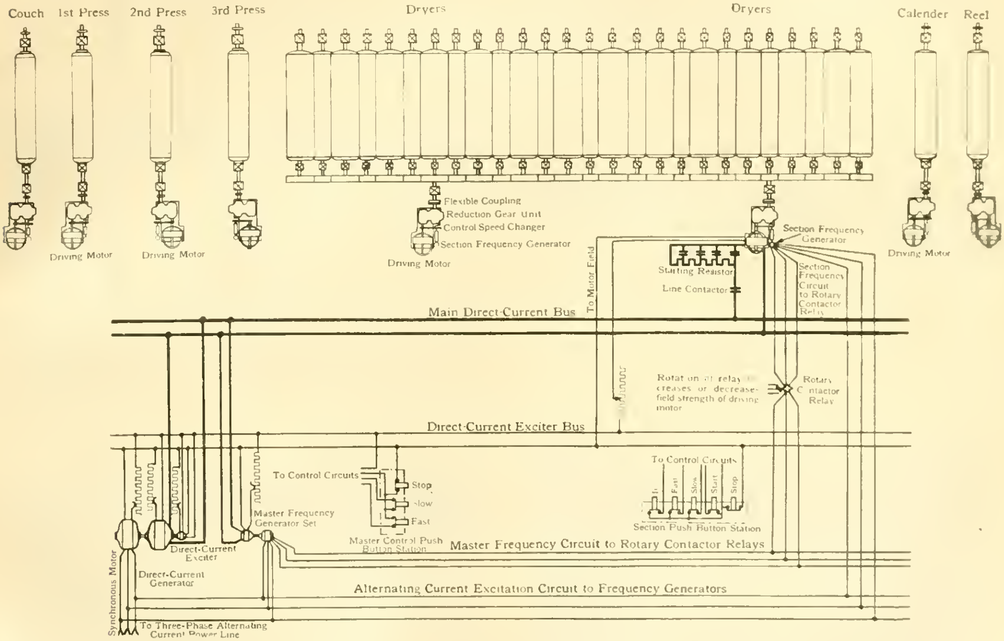


FIG. 5—SCHEMATIC PLAN AND WIRING DIAGRAM OF WESTINGHOUSE SYSTEM OF SECTIONAL INDIVIDUAL MOTOR DRIVE

its own section frequency generator, relay, and motor-operated field rheostat, together with an effective anti-hunting device.

The small frequency generators are all excited by alternating current, but since the master and section frequency generators are excited from the same source, any variations in frequency or voltage of the exciting source have no effect upon the regulation, as they do not disturb the balance of frequencies at the rotary relay. Since no appreciable amount of power is required to operate the rotary relay, these frequency generators are small in size. The small speed changers referred to are of small size, as they do not have to transmit power, but simply overcome bearing friction of the small frequency generator and the friction of regulator to correct anything. However, these changes in speed need not be large enough to be perceptible to the eye or detectable by ordinary indicating apparatus, to actuate this new regulator. In fact, the regulator will detect changes in speed of a few thousandths of one percent, and make the necessary correction immediately, and without any tendency to overtravel or hunt, so that no perceptible change will be found in the draw of any section.

A control board is provided in connection with each paper machine, having a master control panel for the paper machine as a whole, controlling the generator and master frequency generator; and a unit section control panel for each of the section driving motors. Starting equipment is provided on each of these panels, consist-

ing of motor-operated cam accelerating switches with line contactors under the control of suitable push button stations for starting and stopping the individual motors, and the entire paper machine as a whole. The master rheostat, under push button control, provides means for adjusting the speed of the paper machine as a unit, over the entire range of speed. The rotary contactor relay and motor-operated field rheostat for each section is also located on the unit section control panel. The push button stations, arranged conveniently on or near the apparatus, provide means for starting, stopping and obtaining any desired speed of the paper machine in the shortest time and in the most efficient possible manner. In this way and in the elimination of the cumbersome mechanical drive, a great deal has been accomplished in increasing production and improving overall efficiency and economy from every standpoint.

While the paper machine has been one of the last places in paper manufacture to derive the benefits of complete electrification, greater benefits will doubtless accrue from this advanced step in motor and control application than from any other phase of electrification in the paper industry.

Automatic Electric Enameling Oven

Installed at Forderer Cornice Works, San Francisco

ELBERT KRAMER
Industrial Heating Dept.,
Westinghouse Electric & Mfg. Company

THE CLEANLINESS of electricity as a fuel is a recognized virtue. An even greater advantage of electricity over fuels in general, is the reliability of service and its unvarying heat at definite adjustments; together with the simple means of controlling the temperature, as well as the duration of the cycle.

The Forderer Cornice Works of San Francisco, manufacturers of hollow steel doors, interior trims, steel partitions, hollow steel window frames and sashes, have recently installed a kiln-type enameling oven, built along the most modern engineering lines. The interior dimensions of the oven are 8 ft. high, 10 ft. wide and 22 ft. long. Provision is made for the insertion of a heat-insulated barrier spanning the center of the oven, thermally isolating each end. The walls, doors and top are of the double wall construction, being filled with three inches of powdered heat insulation. The floor is of three-eighths inch steel plate, resting on two inches of heat insulation in brick form. There is no through metal between the inner and outer surfaces of the walls, top or doors, except at the junction of the inner and outer walls at either end of the oven.

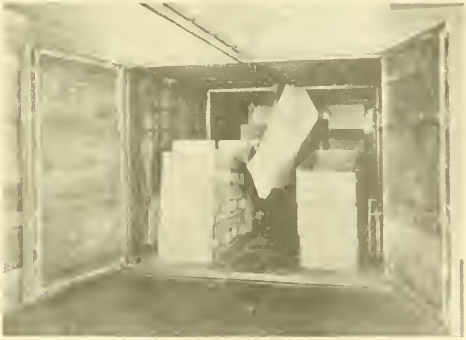


FIG. 1—INTERIOR OF OVEN, SHOWING HEATERS MOUNTED ON SIDE WALLS

One section of the protecting screen is removed. The bus bars are mounted directly over the heaters. The oven is loaded with sections of metal furniture, ready for baking.

FIG. 2—KILN TYPE ENAMELING OVEN RECENTLY INSTALLED IN THE FORDERER CORNICE WORKS OF SAN FRANCISCO

The electrical equipment is arranged to give individual operation to either or both ends of the oven with the heat insulated barrier in place; or, operation in unison, of both ends, with the heat insulated barrier removed. Each end of the oven is controlled by its own bank of heaters, control panel, electric control thermostat system of ventilation (motor driven exhauster, special inlet and exhaust system), door switch and push button station. A time clock is connected for time or cycle control of either or both ends of the oven independently, or both ends in unison.

The heaters are of the open ribbon construction, wound on fire clay bushings, assembled on steel tie rods, the whole supported by pressed steel end plates. The construction of these heaters permits of their being suspended from flanges on the heater end frame, allowing ready expansion and contraction of all parts of the

heater as well as affording a simple means of mounting. Each heater has a capacity of 2.3 kilowatts, there being 32 heaters installed, having a combined capacity of 73.6 kilowatts. The power for the heaters is controlled by a three-pole magnet switch or contactor.

The ventilating system is so designed that the ends, the corners, and the center of the oven, all receive the same degree of ventilation. Cold air enters through the top of the oven, the exhaust air being taken three-fourths from the bottom and one-fourth from the top. The motor for the exhauster is controlled by two single-pole relays. The control circuit for the automatic panel is connected on the motor side of the two relays mentioned above, in such a way that the motor driven exhauster is always operating when the control circuit is energized. A thermostat push button station and door switch are so connected in the control circuit, that the following cycle of operation can be obtained:

FIG. 3—CONTROL PANEL

Consisting of two 125 ampere, three-pole contactors, with relays for automatic temperature control. Two thermostats, one for each half of oven, are mounted to the upper right and left of the panel. Motor driven exhaustors and ventilation ducts are also shown.

With the oven cold, at the start, the thermostat will make contact on the low position. The door switch and push button are closed, the control being completed through the low contact of the thermostat, energizing the control relay, which in turn closes the three-pole magnet switch, or main contactor furnishing power to the heaters. As the oven temperature rises, the thermostat will leave its low position, the three-pole magnet switch, controlling the oven heaters being held in through a mechanical interlock on the control relay. The thermostat, on reaching the high position, short-circuits the control relay, de-energizing the three-pole magnet switch, thereby cutting off the power from the oven heaters. The oven, on again reaching its low or minimum temperature, repeats the above cycle.

It was found necessary and beneficial to have the duration of the bake under automatic time control. The control circuits of both ovens have been so connected with reference to this time switch, that the operator may put under time control either one or both ends of the oven simultaneously with insulated heat barrier in position; or both ends operated in unison with heat barrier removed. This scheme of operation permits the workmen to fill the ovens ready for a bake before closing the shop, the time clock starting and stopping the bake during the night or early morning, the material being thoroughly baked and ready to be taken from the oven when the workmen arrive the next morning. Putting through a bake between closing time of one day and opening time the next morning is a 100 percent saving of labor during the cycle of that particular bake. Another labor saver is the electric control thermostat or, in this particular case, thermostats which keep the temperature of the ovens at a predetermined value.

Determining the proper baking temperature and duration of bake for every color and type of enamel used in their process has enabled the Forderer Cornice Works, with the aid of perfect temperature and time

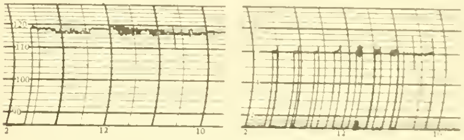


FIG. 4—GRAPHIC METER RECORDS OF VOLTAGE AND CURRENT

The fluctuations in voltage between 11 and 12 were produced by the operation of a motor driven shear and are not characteristic of the heater load.

control, to turn out uniformly finished material. "Spoilage" is an unknown term to this concern.

That the characteristics of this installation may be fully understood, the following operating conditions are given:—

Automatic time, temperature and ventilation control
Power Service, 220 volt, two phase, 60 cycle.
Connected capacity 73.6 kw
Initial temperature 50 degrees F.
Final temperature 200 degrees F.

A bake of 4000 pounds consisting chiefly of hollow steel doors, was placed in the oven, with heat insulating barrier removed. The results of this particular bake were as follows:—

Load, 4000 pounds, hollow steel doors.
Room temperature 47 degrees
Temperature of ovens at end of bake 200 degrees F.
Time required to reach maximum temperature, 35 minutes
Time oven was held at constant temperature (200 degrees F.), 3 hours
Kv-a = (V × I ÷ 1000) = 70.2 kw
Actual kw. (Watt-hour Meter) = 69.82 kw.
Power factor of heaters $= \frac{69.82}{70.2} = 98.5$ percent.
Power consumed for entire bake = 100 kw-hr. for 4000 pounds metal baked.
Power consumption per pound of metal baked $= \frac{100}{4000} =$ 0.025 kw-hr.
Pounds of metal per kw-hr. = 40.

Renewal of the Catenary Construction in the Hoosac Tunnel

L. C. WINSHIP
Electrical Superintendent
Boston & Maine Railroad.

NINE years of exposure to gas, moisture and corrosive solutions from the tunnel roof have been sufficient to take the life of the copper messenger, which was installed in the Hoosac Tunnel at the time of the electrification in 1911. This messenger, practically severed in many places and materially weakened throughout its entire length, has now given place to another, similar in nature, but protected in such a way as to give promise of a much longer life.

Electrical conductivity and resistance to corrosion were two features which received particular consideration in the determination of a type of construction which would be suitable for this location. Auxiliary feeders were not to be provided and the corrosive action of the smoke and moisture, which would be present to some extent, must be guarded against. The type of construction which was finally developed consisted of suspended brackets carrying double insulation and a conducting system made up of a hard drawn copper messenger of seventeen strands and 300 000 circular mil cross section, from which were suspended two 4-0 grooved Phono-electric trolley wires. The trolley hangers, insulator pins, studs and messenger clamps were of bronze, the brackets were covered with tape and painted, and the remaining fittings, which were of iron, were galvanized and painted.

The tunnel operation provides for the handling of the steam locomotive with the train, and although this locomotive is ordinarily not working, a small amount of moisture and gas is given off, which tends to collect on and around the overhead construction.

During the warmer months, the ventilating fan at the central shaft draws in the warm air through the tunnel portals and, as the temperature of this air drops in its passage to the shaft, the moisture condenses on the catenary structure. This moisture tends to fix a certain amount of dust from the air, together with the sulphur gas which comes from the locomotives, to such an extent that a material deposit, highly acid in nature, is built up on the conductors. This deposit effects a very general and extensive deterioration which, while more rapid during the summer, continues to some extent throughout the entire year.

Much more serious than this action, however, was one which has occurred at a number of definite points in the tunnel, and which has been manifested by the gradual disintegration of the messenger over a length varying from four to six inches. The individual strands in this short length would successively part under strain as their section became inadequate and, in several instances, the action progressed undiscovered until the messenger had been completely severed. This type of failure was first noticed in 1913, and the peculiar action leading towards it has been a source of concern ever since. In the attempt to guard against complete failure of the messenger, close inspections have been made and re-enforcements to the number of about one hundred have been applied at the points where this local deterioration has been in evidence. Subsequent inspections have shown similar deterioration of the re-enforcing member at the same point as on the messenger and, in at least one instance, this has been manifest in the second re-enforcement.

While the cause of this peculiar condition has not been determined, it appears that the water from the tunnel roof is one factor. Whether or not this moisture tends to fix more effectively the corrosive agent in the atmosphere, or comes as an active solution from the rock of the tunnel roof, is still a subject for investigation.

This gradual and intensive deterioration of the messenger had progressed to such a point in the fall of 1919 as to make evident the necessity of a complete replacement inside of the next twelve months, and steps were taken looking towards a possible improvement upon the original installation. As equivalent conductivity must be maintained, the choice of material was limited to copper, and the problem then seemed to be one of adequately protecting this copper from the corrosive agents. Such protection appeared to be possible through the use of special paints or similar preparations and a number of these preparations were given a test in the tunnel during a part of 1920. One of these, a viscous and non-hardening compound, appeared to have the qualities which would make it suitable.

With this idea of protection particularly in mind, the specifications of the new messenger were so drawn as to provide for the tinning of the strands and the covering of the messenger with one serving of braid, this braid to be impregnated with a weather proofing compound. In addition a heavy coat of the protective compound was to be applied after the installation.

The necessity of the renewal of the trolley hangers and the trolley was not as pressing as that of the messenger, as the hangers for the most part were in serviceable condition and the wear of the trolley wire, except at a few points, had reached only about one-half of that allowable. The corrosion on the top of the trolley wire had progressed, however, to such an extent as to produce a loosening of the clips in a number of

instances, and a renewal in about two years was indicated.

While it would have been possible with the replacement of the hanger clips to have installed a new messenger with the old hangers and trolley wire, the labor charge and the cost of the delay which would result from the withdrawal of one track from service, a large part of which would have again been incurred within a comparatively short time with the renewal of the trolley wire, made it advisable to sacrifice such service as remained in the hangers and the trolley wire and make a complete replacement. Also, as a part of this replacement, to protect the messenger wire in such a way as to make its life equal to that of the hangers and the trolley wire. Consequently new hangers and trolley wire like those of the original installation were provided.

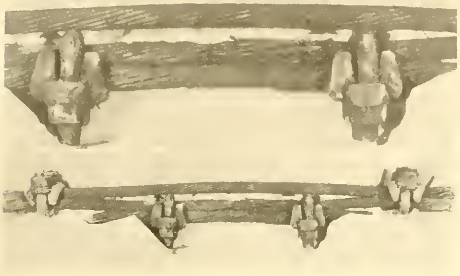


FIG. 1—SECTIONS OF THE TUNNEL MESSENGER WITH TWO REINFORCEMENTS

Inasmuch as electrical operation through the tunnel had to be maintained at all times, it was necessary that the work be laid out and carried forward in such a way as to provide not only for this continuity of service, but for the safety of the men of the construction force. The arrangement provided for the release of one track for eight hours per day, the removal of power from the wire over this track and the adequate grounding of these wires at each portal of the Tunnel. Additional grounds were provided on the construction train which could be attached to both the insulator brackets and the trolley wires, these connections being required to take care of the voltage which might be present on a bracket due to a defective insulator over the adjacent track, as well as the voltage produced on the trolley wires by induction. These ground connections also afforded protection in case the wire was accidentally energized by the bridging over of a section break by an electric locomotive. These safeguards, together with close supervision, made possible the completion of the work without injury to any one of the force.

The construction train was made up of one gondola car, two box cars, and from four to seven flat cars equipped with staging. The gondola car was used for the reels of wire, one of the box cars for tools, and the other for scrap material. The necessary illumination was provided by acetylene lights. This train was handled by a steam locomotive and in order that the amount of smoke might be as small as possible, a very heavy fire was built up immediately prior to entering the tunnel, which made possible such movements as were necessary during an interval of two or three hours without additional firing. Varying tunnel draft conditions were also taken advantage of and as a result of these precautions, it was possible to carry forward the work without the aid of special ventilating apparatus on the construction train and without serious interference by smoke.

The messenger cable was first run out and pulled so that the sag between the suspension points was slightly less than that of the old messenger wire, temporary fastenings were made at each insulator and the two messengers temporarily tied together at intermediate points. The trolley wires were next run out, the movement of the train being so regulated as to supply this trolley in about two hundred foot sections. These were also pulled in such a way as to make the height above the rail at the center of the span about two inches greater than that at the insulator, allowance thus being made for a certain amount of elongation in both the messenger and trolley wires. The old messenger was then removed from the insulator clamps and the new put into place and fastened. The new hangers were applied and clipped in and the section of the old construction cut free and dropped to the top of the staging where it was further cut, at the hangers, into lengths of about ten feet, both for convenient handling as well as the easy separation of the hangers from the rest of the material as these appeared to be worth reclaiming. The presence of the live trolley wire over the adjacent

FIG. 2—SECTIONS OF THE TUNNEL MESSENGER WITH SINGLE REINFORCEMENT

track called for extreme care in the removal of this material and consequently no attempt was made to handle the old wire otherwise than in short sections.

At the close of the day's work, the trolley wires were dead ended and so fastened to the old trolley wires at the point where the clipping in was discontinued as to make possible the easy movement of the

trolley shoe from the old to the new construction. This connection was made in such a way that no difficulty was experienced in restoring the line to service immediately upon the withdrawal of the work train.

To preserve the continuity of the braid on the messenger as far as possible, contact at each hanger was provided by simply removing from the lower side of the messenger a section of the braid of the same size as the contact plate on the top of the hanger rod. Great care was taken to make a nice fit at this point, and in case the braid was torn in applying the hanger, tape was applied to cover the exposed part of the messenger. All other exposed portions of the messenger were similarly covered with tape.

FIG. 3—BRONZE TROLLEY HANGER
Showing the progress of corrosion.

The corrosion of the top of the trolley wire, indicating that the reduction in metal at the top rather than at the bottom, would determine the length of service, suggested the protection of the top of the new trolley wire with a coating of the same preparation as that applied to the messenger, and it subsequently appeared advisable to extend this treatment to the hangers, brackets and other details of the construction. The behavior of this protective coating will be watched very carefully to determine whether or not periodic applications to messenger, hangers and trolley wire may not make further renewals unnecessary until such time as the trolley wire is worn to the safe limit.

INCREASING TROLLEY CLEARANCE

During the past few years the clearance between the top of the rail and the trolley wire has been maintained at fifteen feet, six inches and a published clearance of fourteen feet, eight inches has controlled the height of equipment through the tunnel with especial reference to brake staffs. As a large number of the cars from foreign roads moving towards New England are fitted with brake staffs slightly in excess of fourteen feet eight inches, it has been necessary either to shorten these staffs or reroute the cars around the tunnel. As a very large percent of these high brake staffs were fifteen feet and less above the rail, it appeared that an increase of clearance of only four inches would result in a considerable saving in the cost of cutting off staffs or rerouting the equipment.

Roof clearances above the insulators and messenger wire were such as to make the increase possible, except at a few points, and it appeared that this additional four inches could be obtained by simply raising the secondary insulators and with them the transverse brackets which supported the primary insulators and the messenger wire. As the equipment and construction force which were used in the wire renewal would be available for this increase in clearance, it was evident that the cost of this work would be comparatively light, and arrangements were made to proceed therewith as soon as the new wire was in place.

The original clearances between the rail and the trolley wire were not absolutely uniform, and to obtain the desired four inch increase, it was necessary to raise the brackets two, four and six inches, as the particular location demanded. The work was necessarily carried on from one track, and care had to be exercised to prevent the breakage of insulators and interference with the energized line over the other track. The stud was removed from the secondary insulator pin, a jack was then placed under the end of the transverse bracket and this end so raised as to permit the insertion of a two inch block between the insulator pin and the supporting hanger. A longer stud was then applied and secured. The flexibility of the structure was such as to make this rise of two inches practicable without endangering the secondary insulator over the other track.

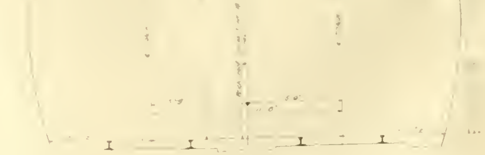


FIG. 4—CROSS SECTION OF HOOSAC TUNNEL, SHOWING CLEARANCES

but as lifts in excess of this amount were not considered safe, it was necessary to make this two inch lift at all points on one track, then a four inch lift with the insertion of a four inch block on the other track, and finally a second two inch lift on the first track with the addition of a second two inch block. At points where six inch blocks were required, the method of procedure

was similar. The length of the train was such as to make possible the working on three brackets at a time.

At points in the tunnel where the clearance between the top of the insulator and the tunnel roof was already a minimum, a shorter primary insulator was installed, and the secondary insulators then raised. As the increase in height effected by raising the secondary insulators was practically compensated by the shorter primary insulator, it was necessary to shorten the trolley hangers in both sections of the catenary adjacent to the insulator in order to provide the desired increase in clearance. The clearance between the trolley wire and the bracket with the original insulator was so small as to make impracticable the raising of the trolley wire through the shortening of the hangers, except with the installation of a shorter insulator.

The final clearance between the insulator caps and the roof, and between the messenger and the roof, at points in the spans were, in many instances considerably less than those thought necessary when the original installation was contemplated, the present minimum being about six inches as compared with the proposed minimum of twelve inches, but past experience has indicated that these lesser clearances are sufficient.

The raising of the trolley wire brought with it a corresponding rise in running position of the locomotive trolley shoe and a very decided decrease in clearance between the trolley horn and the tunnel roof was experienced at many places. The close points were located and, where existing in the rock, additional clearance was readily provided by chipping. In the brick work these close clearances cannot readily be increased and it is there necessary to operate with a six inch minimum. While this appears to be somewhat hazardous, no serious results are expected as long as the proper alignment and surface of the track is maintained.

Eleven thousand volt electrification of the Hoosac Tunnel was undertaken with no little concern with respect to the behavior of the insulators and the catenary material, and much thought was given to the details of a construction which would meet the exacting conditions. The ease with which this construction has been maintained has justified its use. The renewal and readjustment which was begun October 7th and continued until December 7th, 1920 was the first heavy piece of maintenance work which has been carried forward since installation in 1911. Protection has now been provided for the material which, it is expected, will result in even easier maintenance and much longer life.

Principles and Characteristics of Synchronous Motors

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Power Engineering Dept.
Westinghouse Electric & Mfg. Co.

THE PRINCIPLE of a synchronous motor is sometimes referred to as the reverse of the operation of a synchronous generator. While this is quite true, broadly speaking, the conception of the action of an alternator is very often made up of ideas of voltage and reactance relations, whereas the fundamental elements for the production of torques are flux and current. It seems, therefore, that the clearest insight into these principles can be obtained by means of certain conceptions of the internal action of the fluxes and currents flowing in the motor under various conditions.

With the exception of a relatively small resistance drop, the terminal voltage of any synchronous machine is the result of the cutting of the armature conductors by the main air-gap flux and by the leakage flux set up by the armature current. As a matter of fact there is no strict line of demarcation between the two fluxes mentioned, and it is a difficult matter to distinguish between them, either from the design of a machine or from its tests. For the present, the armature leakage flux will be neglected and it will be assumed that all the fluxes, actually more or less dispersed, have been replaced by a single flux crossing the air-gap in the same relative phase position as the resultant of the actual fluxes. This equivalent flux will be of a magnitude directly proportional to the terminal voltage and its phase position, considered as a vector, will be fixed with respect to that of the applied voltage, regardless of the conditions under which the machine operates. By this conception the main principles can be explained, while afterwards the modifications due to the leakage flux will be taken up.

It is a fundamental law that forces are exerted when conductors carrying current are located in a magnetic field. Their direction is at right angles to the direction of the flux and they are proportional to the product of the flux and the current involved. Thus, the torque of a direct-current motor is produced by the armature conductors carrying current being located in the main field flux and the current directions under alternate poles are controlled by the setting of the brushes on the commutator. Except on this latter point the torque of a synchronous motor is produced in essentially the same manner; the equivalent flux, crossing the air-gap radially, exerts tangential forces on any

current-carrying conductor located on the surface of the armature. To produce its maximum effect the current, considered vectorially, must be located directly on the axis of this flux; or the torque produced by any current is proportional to its component located on the flux axis. The angular position of the current with respect to the flux axis is controlled by the variation of excitation.

The idea of the revolving field used in connection with the study of the principles of induction motor operation is, of course, entirely applicable to the case of synchronous motors, so that the effect of the currents in the armature conductors, rising and declining in successive groups of coils, can be considered as that of a current revolving in the armature at synchronous speed, and taking up various positions with respect to the flux to correspond in phase position to the various conditions of load and power-factor.

Let Fig. 1 (a), for instance, represent diagrammatically a synchronous motor operating without mechanical load and with the normal excitation for this

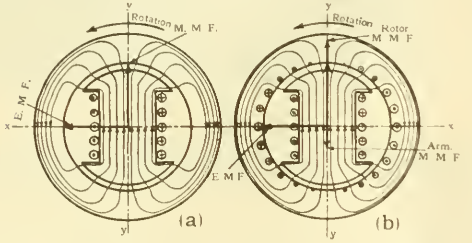

FIG. 1 (a) DIAGRAMMATICAL REPRESENTATION OF SYNCHRONOUS MOTOR
Operating without mechanical load with normal excitation.

FIG. 1 (b)—MOTOR OPERATING WITHOUT MECHANICAL LOAD WITH INCREASED EXCITATION
Size of circles corresponds to value of current

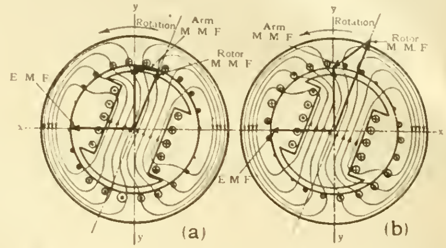

FIG. 2 (a)—ROTOR DISPLACED FROM NO-LOAD POSITION DUE TO AN APPLIED MECHANICAL LOAD

FIG. 2 (b)—SYNCHRONOUS CONDENSER SUPPLYING MAGNETIZATION TO THE LINE

condition. Assuming the theoretical case when there are no losses within the machine itself, the armature current will be zero; so that the only source of m.m.f. is the current in the field windings and the rotor flux is consequently identical with the equivalent flux. If, in the figure, *y-y* is the axis of flux corresponding to the impressed voltage, the rotor must take up the position corresponding to this axis, as indicated. If it attempts to take up any other position, armature currents will flow and torques will be produced tending to return it to this position and as there are no external torques applied to the shaft, the rotor will not resist these restraining forces.

If the field excitation be increased, the flux will tend to increase beyond the magnitude of the equivalent flux, and as a consequence an armature current will flow producing a m.m.f. equal and opposite to the increase in field m.m.f. This current has a demagnetizing effect upon the field and will assume the phase position of the axis *x-x* at right angles to the flux, as shown in Fig. 1 (b). On account of this phase position the current can produce no resultant torque and consequently there will be no change of the position of the rotor. If, on the other hand, the field excitation be reduced below the normal value the opposite action results, the armature current will flow in the reverse direction and become magnetizing instead of demagnetizing, but still counterbalancing the tendency of the flux to change its magnitude.

It will be observed from the foregoing that when the rotor excitation is increased, the excess of magnetization beyond that of the equivalent flux cannot be retained within the machine itself but is transferred in the form of reactive currents to the external circuit. When the motor is under-excited the reverse is true and the complementary magnetization is drawn from the external circuit. This property is utilized in the synchronous condenser for controlling the power-factor of distributing and transmission systems by supplying them with magnetization only. Usually the condenser is located as close as practicable to the point where the magnetization is required. The synchronous condenser is simply a form of synchronous motor, except that the design proportions are such that the ratio of the magnetization supplied externally to the magnetization required within the machine is as great as possible.

When a mechanical load is applied to the shaft of a synchronous motor the rotor immediately begins to drop back in phase position. The action is quite unlike the "slip" of an induction motor; for in the latter case the speed of the rotor can never reach synchronous speed and the torque is developed only by the continued dropping back of the rotor behind the revolving field and is a function of the resulting difference of velocity. In the case of a synchronous motor changes of speed are transient and occur only with changes of load. When stable conditions are regained the speed again becomes synchronous although the rotor may have become permanently displaced with respect to the revolving field. The torque, on the other hand, is a function of the relative phase positions of the rotor and the revolving field. The torque increases as the displacement between the two increases until a maximum or pull-out

value is reached. This point is taken up at a greater length in the following paragraphs.

Fig. 2 (a) represents the rotor displaced from its no-load position due to an applied mechanical load. As the rotor drops back it tends to take the flux with it; therefore, to restore the flux to its constant equivalent value, a current appears in the armature, increasing as the displacement increases, and producing an m.m.f. just equal to the change of m.m.f. caused by the rotor displacement. To show this in a more definite manner it is convenient to resolve the m.m.f.'s of the armature and rotor into relative components along the axes *x-x* and *y-y*. Since *y-y* is the axis of equivalent flux, the resultant component of flux and m.m.f. along *x-x* must be zero; or, in other words, the components of m.m.f. of the armature and the rotor along this axis must counterbalance each other. If the applied voltage is assumed constant, and the reluctance of the magnetic

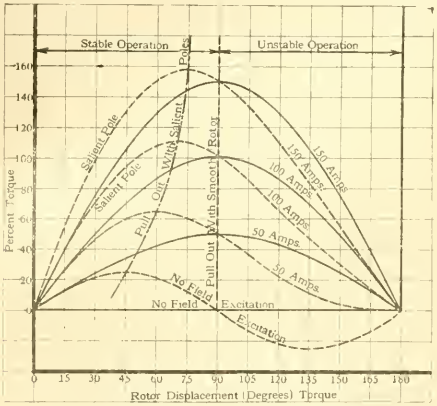

FIG. 3—ROTOR DISPLACEMENT AND TORQUE FOR VARIOUS VALUES OF EXCITATION AND CONSTANT IMPRESSED VOLTAGE

circuit is assumed uniform, the resultant m.m.f. along *y-y* must be constant. Applying these two limitations to all conditions of operation the internal actions and reactions may be analysed. It will be seen that when the rotor drops back, its m.m.f. has a component along the *x-x* axis which must be neutralized by the m.m.f. of a current flowing in the armature corresponding in phase to the axis *y-y*. This current is directly proportional to the field excitation multiplied by the sine of the displacement angle. In addition, if the excitation be normal for no-load, its *y-y* component will be insufficient for the amount of flux required, and a small component of armature current will appear at *x-x* to complete the magnetization of the field. The actual current in the armature is the resultant of these two components. The torque produced is proportional to that component of armature current located on the *y-y* axis, for it is placed directly in the flux. This component is proportional to the *x-x* component of rotor m.m.f., as stated above, so that the torque is also proportional to this latter value. If the rotor m.m.f. be increased it will take a correspondingly smaller displacement to give the same torque-producing component, and the rotor will move slightly forward. Thus, for a given torque, the displacement depends upon the excitation; the greater the excitation, the less the displacement.

In addition to this action, when the excitation is increased the magnetizing component of the armature current may decrease to zero or even reverse and become demagnetizing with respect to the rotor. In this manner magnetization may be supplied to the line, as in the case of the synchronous condenser, Fig. 2 (b).

In Fig. 3, the curves in full lines show the relation between displacement and torque for various values of excitation with a smooth rotor, as has already been indicated. With zero excitation no torque can be produced by synchronous action under the conditions assumed. When excitation has been applied, it will be seen that the torque increases as a function of the displacement (a sine function) and reaches a maximum value when the displacement is 90 degrees. This is the

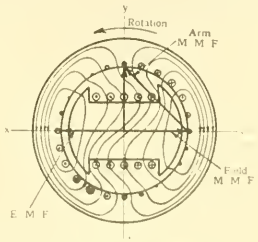

FIG. 4—REACTIVE COMPONENT OF ARMATURE CURRENT AT POINT OF PULL OUT

Producing all of the magnetization for the equivalent flux

point at which the whole rotor m.m.f. is acting transversely and so causes the flow of the maximum torque-producing component of armature current. If this displacement be exceeded the transverse component of rotor m.m.f. will decrease, and with it the torque; so that the motor operates in an unstable condition. The maximum torque is called the pull-out torque, and if this be exceeded the motor will come to rest. The pull-out torque is proportional to the field excitation and to the equivalent flux, regardless of the power-factor at the motor terminals. Indeed, at the point of pull-out, the whole of the magnetization for the equivalent flux is produced by the reactive component of armature current, Fig. 4, just as is always the case for an induction motor. The curves of Fig. 3 are plotted on the assumption of a constant impressed voltage. If this voltage varies, the equivalent flux and consequently the pull-out torque will vary directly with it. This is one point of difference from the induction motor, where the pull-out torque varies as the square of the impressed voltage. When running on reduced voltage, the synchronous motor will have a relatively greater pull-out torque. This does not necessarily mean, however, that a synchronous motor should be used on systems subject

to large drops in voltage; for while the pull-out torque of the synchronous motor may suffer the lesser decrease under such conditions, its speed is constant, while that of the induction motor will drop considerably as the load is increased and, in the case of motor-generator sets especially, this drop in speed means a drop

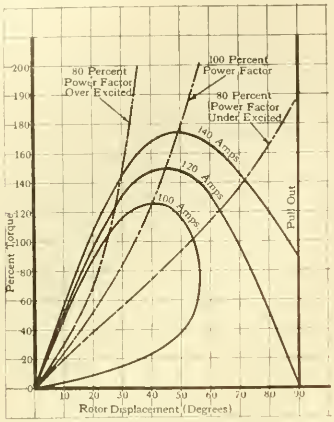

FIG. 5—RELATION BETWEEN TORQUE AND ROTOR DISPLACEMENT
For given values of armature current, when the load and excitation are varied.

in the torque which may more than compensate for the extra pull-out torque of the synchronous motor. In addition, momentary drops of voltage will have far more serious effects on a synchronous motor, for if it once falls out of step there is less tendency for it to synchronize again.

Two of the primary assumptions made in this analysis should be taken up in more detail; these are, the uniformity of the reluctance of the magnetic circuit, and the negligence of the armature leakage fluxes.

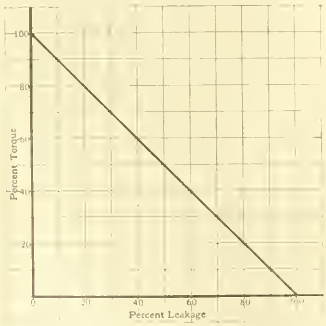

FIG. 6—RELATION BETWEEN TORQUE AND PERCENT LEAKAGE
For a given excitation and rotor displacement.

Practically all synchronous motors are of the salient pole type, so that the reluctance of the magnetic circuit taken at a point directly under the pole is considerably less than when taken in the interpolar space. This non-uniformity of reluctance can produce a reaction even when the rotor is unexcited, which may enable the motor to operate under partial load at synchronous speed. Consider, for a moment, the case of a load being applied to the unexcited motor. The flux is caused to flow by a magnetizing current located on the x-x axis. When the rotor drops back, although the m.m.f. is along the y-y axis, the flux will tend to take a path more nearly coinciding with the axis of the salient poles on account of the reduced reluctance there. Therefore, to force the flux back to its normal axis the torque-producing component of current will appear at y-y. The maximum dissymmetry of reluctance occurs when the rotor has dropped back 45 degrees and this is the point of maximum torque beyond which pull-out occurs. This maximum torque is dependent upon the ratio of reluctances of the magnetic path with the rotor in the two extreme positions 90 degrees apart. Some motors can be loaded up to 30 or 40 percent or their normal rated loads without pulling-out, although the corresponding torques are a much smaller percentage of the actual pull-out torques in the excited condition. The effect of this non-uniform re-

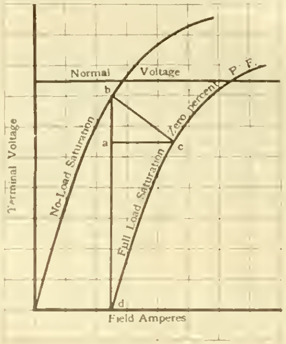

FIG. 7—NO-LOAD AND FULL-LOAD ZERO PERCENT POWER-FACTOR SATURATION CURVES

luctance shows itself even when the rotor is excited, as is indicated by the curves of Fig. 3 in dotted lines. These curves show that the angle of pull-out varies with the excitation, and that the form of the curve in the stable and unstable portions is unsymmetrical.

The second assumption requiring special attention is that there is no armature leakage flux. This flux is set up, in the actual motor, by the armature current alone, in paths distinct from the magnetic circuit of the rotor, and which, for a given armature current, is almost entirely unaffected by changes of rotor excitation or phase positions. Because of this it is not instrumental in the production of torque, and simply represents a definite amount of magnetization in the machine proportional to the current.

The main result of leakage is the reduction of armature reaction and torque. Take, for instance, the explanation referring to Fig. 2 (a). It was stated that as the rotor became displaced its m.m.f. component along x-x must be counterbalanced by an armature m.m.f. to bring the air-gap flux back to its constant position in

space. When leakage is present, however, the armature counter m.m.f. exerted need be sufficient only to bring the flux part way back, the remaining difference between the air-gap flux and the equivalent flux being made up by the leakage flux in external paths. Thus for a given rotor excitation and displacement the armature counter m.m.f. and current, and the resulting torque all decrease with an increase in the magnetic leakage of the armature. If, with the rotor unexcited and with a given armature current, the ratio of the leakage flux to the total flux be known as the percent leakage, the decrease in torque for a given excitation and displacement is in a direct proportion to the percent leakage, as is indicated by Fig. 6. This means that to obtain a given pull-out torque, a machine having a greater percent leakage must be supplied with correspondingly increased excitation over that supplied to a motor with a smaller leakage. This relation is much more frequently considered in connection with induction motors than with synchronous motors, but it is equally applicable in either case.

Leakage reactance acts in exactly the same way as a reactance external to the machine. Thus, if there be a reactance intervening between the source of constant voltage and the motor terminals, the total reactance of this and the internal leakage should be added together to find the decrease of torque. In certain instances the intervening reactance between two synchronous machines or systems of synchronous machines has reached so great a value that the maximum synchronizing power which can be transmitted is insufficient to prevent serious hunting of one with respect to the other.

Fig. 7 shows more clearly what is meant by the term "percent leakage". This diagram represents the no-load and full-load zero percent power-factor saturation curves for a synchronous motor. The triangle *abc* is what is generally known as Potier's triangle, by which in some measure the leakage reactance and the reaction may be segregated.* If, then, *ab* is a measure of the leakage fluxes and *bd* a measure of the total fluxes due to the armature current alone, then the ratio $\frac{100\ ba}{bd}$ is the percent leakage flux, and the torque under the conditions will be decreased in the ratio $\frac{ad}{bd}$.

In considering reaction and armature reactance, perhaps the simplest theoretical distinction can be drawn from the fact that reaction is a necessary adjunct in the production of torque, while reactance always tends to decrease it. It must not be considered that internal reactance is wholly undesirable. It serves the purpose, in any synchronous machine, of reducing the initial rush of current on occasions of short-circuit.

*See artical by the Author in the JOURNAL for Feb. 21, p. 60.

The curves of Fig. 5 are drawn to show the relation between torque and displacement for given values of armature current when the mechanical load and excitation are varied. It is clearly indicated that unless the armature current increases beyond a definite value, which is the amount required for self excitation under the pull-out condition, the motor will not pull-out. As long as the field current is greater than that required for unity power-factor, the motor cannot pull-out.

A high ratio of pull-out torque to normal or rated torque is generally desirable, and in cases of motors subject to sudden heavy overloads it is necessary. As the pull-out torque depends upon excitation it means that for the condition of normal load the excitation must be relatively high when compared with the amount actually required from other considerations; or, in other words, the rotor displacement at the normal load must be relatively small. In relation to design this tends to produce a rather larger machine than would otherwise be required. The inherent stability may thus be obtained by one of the following methods; first, taking the larger machine and simply under-rating it; second, designing a machine of more nearly ordinary proportions but with an exceptionally wide air-gap in which to consume the extra excitation. Where magnetization would be of service to the external system in raising its power-factor, the latter condition is in a broad sense wasteful of excitation, for it is using up magnetic energy in the increased air-gap which might be transferred to the external system. The third method, then, is to design the machine to carry the reactive components of current and to operate it at a leading power-factor (with respect to the system). This will also insure a high power-factor even on severely heavy overloads.

In certain instances of late a scheme of over-compounding the excitation has been used in the case of motor-generator sets, especially those intended for railroad substation service. The motor is excited by a separate exciter furnished, in addition to a shunt field winding with a series field winding energized by the main current from the direct-current generator, and in this way the exciter voltage rises automatically with increases of load. The resulting increase of field current in the motor renders the inherent pull-out torque a function of the load applied to the motor.

In the design of synchronous condensers no particular attention need be paid to the pull-out torque, for the machine is intended to be operated with little or no mechanical load. On this account the air-gap may be made relatively smaller than for a synchronous motor, unless special conditions of operation with greatly reduced excitation are contemplated, when the air-gap must be made great enough to ensure stability under the worst operating condition.

Experience in Drying Out Large Transformers

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Westinghouse Electric International Company

ENGINEERS are frequently obliged to dry out high-voltage transformers when the only available method is by external heating. There are two ways by which this can be accomplished:—

1—Drying the transformer assembled in its case.

2—Drying the transformer outside its case, and assembling it after it has been dried.

This article deals with an experience the writer had in France, in drying out a number of 6000 kv-a, single-phase, 10 000 to 70 000 volt, oil insulated, water cooled transformers at two outdoor sub-stations.

The transformers in question had been enroute from Pittsburgh, or outdoors in their packing cases at customer's station for two years. Prior to the writer's arrival, the contractor had attempted to dry out these transformers by blowing hot air through a hole at one end of the packing case and an outlet at the other, with the transformers on their sides. He succeeded in burning out two transformers. The writer used successfully the second method mentioned above.

Each station has a small transformer house provided with a hoist for assembling and repairing the transformers. Each assembled transformer is furnished with wheel bases, by means of which it is pushed from its foundation onto a special truck, which is on a track leading into the transformer house. Two trucks were available at each station.

A transformer core was removed from its packing case and the packing case bottom with its heavy timber was placed upon one of the trucks. In the center of this bottom, between the timbers, a square hole was cut. A wooden conduit was then built between the timbers, around three sides of the hole, and out to one end, where it connected with a larger double wooden conduit, which extended into the box containing the resistance. At the end of the resistance box (which extended two feet beyond the resistance) a motor operated fan was placed, as shown in Fig. 1.

The transformer core was placed right side up, over the hole on the truck, and enclosed tightly in a wooden case. The case had four detachable sides held together by bolts as shown, so that it could easily be assembled and used for all transformers. The top of the case had holes to allow for the escape of air. Two doors were constructed at the bottom and one near the top of the case to allow for observation of temperature, etc.

The resistance used was "home-made", iron wire being coiled into spirals and strung over spool insulators. Each unit (there being one unit at each station) consisted of three similar resistances, and each resistance was connected to a three-phase line through fuses and switches. One resistance was connected in delta, another in star and the other in uneven Z, so that, by opening switches or removing fuses, any regulation of temperature could be made. The total power used in this case was approximately 75 kw.

The wooden conduit connecting the resistance box to the conduit under the transformer was made double for conservation of heat. Removable covers were made to the double conduit and resistance box, in order that the interiors might be accessible. The resistance box and conduit were lined with asbestos, as far up as the transformer case. This reduced the fire risk and also kept the heat where it was most needed.

Common window screen, built into a frame, so that it could be removed for cleaning, was placed at the intake to the fan and at the entrance to the resistance box. Another window screen was constructed in a deep frame next to the resistance, on the fan side. This system compelled the air to pass through the center of the

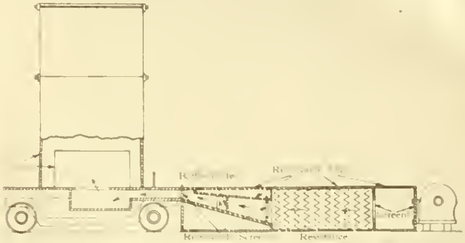

FIG. 1—ARRANGEMENT OF APPARATUS FOR DRYING OUT LARGE TRANSFORMERS

resistance, instead of around the edges, and thereby increased the uniformity of heat. A hinge door was placed at the intake to fan, which was raised and lowered to regulate the volume of air.

In the double conduit, as shown, were placed two screens of fine copper wire, in sliding frames. It was found necessary to remove and clean these screens, at least every other day. Otherwise, dust collecting on the screens would retard the air and cause a greater difference in temperature between the resistance and the transformer case.

At first, it was found that the temperature of the air entering the transformer case varied greatly at different points—to such an extent that the air at the hottest point would have to be dangerously hot in order to heat the coils sufficiently. To eliminate this condition, baffle-plates were arranged in the double conduit, as shown. Then at no place of entrance to the transformer case did the temperature of the air vary more than one or two degrees. The temperature of the air entering the double conduit, of course, varied

more—the hottest current being near the center of the entrance.

With the above system in operation, the following results were easily obtained with a fan of about 2000 cubic feet per minute capacity. The average temperature of the air leaving the resistance was from one to two degrees higher than the air entering the transformer case, which was kept around 85 degrees C. The coil temperature was from 70 to 80 degrees C. The temperature of the coils at the top was not more than two degrees lower than the temperature at the bottom. The screens kept dust from entering the transformer and the heat was so well placed that the observers were obliged to have extra heat in the room to keep warm.

Wires were placed on insulators at the top of the transformer case and passed through holes in the top and connected to the windings and iron for testing purpose. Each transformer was dried out for about a month until the megohms resistance had attained a safe and constant value.

The Development of Magnetic Materials

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THE MATERIAL used by the pioneers in the field of electromagnetism was naturally the iron already available at the time, either cast iron or wrought iron. Some grades were found to be better than others, thus soft wrought iron was found to have better magnetic properties than iron high in carbon, and the lower the carbon content the better. Swedish charcoal iron was considered the best iron for magnetic purposes during the latter part of the 19th century. The introduction of the Bessemer process did not alter this situation, and it was only the coming of the modern open hearth furnace that enabled steel makers to produce a material equal in magnetic properties to the old Swedish iron. The temperature produced in this furnace was high enough actually to melt pure iron and this could be poured into ingot forms, thus producing what was called ingot iron. The various grades of iron, as tested by Ewing and others, would have a maximum magnetic permeability of 2-3000 and a hysteresis loss of 3-5000 ergs per c.c. per cycle for B = 10 000 and, on account of the low electric resistance, would have a high eddy current loss.

This was the situation at the close of the nineteenth century at the time when the development of electromagnetic machinery was increasing at a tremendous rate. For dynamo-electrical machinery the magnetic properties of the existing materials caused little trouble, for the simple reason that the large air-gap in the magnetic circuit is the all important factor in the determination of its equivalent permeability, and the mechanical losses due to rotation largely influence the efficiency of the machine. Consequently, while iron with high permeability and low losses is desired, it could not greatly improve the performance of this class of machine. This is proved by the fact that even today the designers of motors and generators are satisfied with low silicon steel.

With transformers, however, the story is very different. Here there is a closed magnetic circuit with no moving parts, so that its performance depends entirely upon the characteristics of the iron, considering those of the copper constant. Even the earliest transformers were built with thin sheets for the cores, in order to cut down the eddy currents, but other than that no great improvement was made for some time. The best transformer sheet was made from Swedish charcoal iron having a maximum permeability of 2800 and a hysteresis loss of 3400 ergs per c.c. cycle. Another material was developed in England (by J. Sankey & Sons) called "Lohys" having a maximum permeability of 2800 and a hysteresis loss of about 3000 ergs per c.c. per cycle (a total iron loss of 3.56 watts per kg for B = 10 000 at 60 cycles). The aging properties of these materials were such that the losses would sometimes double in a few months, necessitating dismantling the transformer and reannealing the iron. If this was not done the energy losses rose to 10 or 15 percent of the capacity of the transformer[1].

This condition of affairs attracted the attention of one of the greatest steel makers of his time, Robert A. Hadfield of Sheffield, England. Prior to 1865 iron metallurgy was confined exclusively to the combination of iron and carbon. In 1882 Hadfield commenced an investigation of the effect of other elements upon the mechanical properties of iron, in the course of which he discovered the famous manganese-steel, containing 12 percent Mn, and possessing, after quenching, unusual strength combined with wonderful toughness (the elongation amounting to 100 percent). Another unusual property of this alloy was that it was non-magnetic at ordinary temperatures, and was, therefore, admirably adapted for use in the proximity of compasses on shipboard. His contribution to the development of armor plate and armor piercing projectiles has been of vast importance and was the result of his research work on iron alloys of many different types, including nickel, chromium, tungsten, cobalt, molybdenum and others.

[1] Hadfield: History of the Metallurgy of Iron & Steel—*Proc. Inst. Mech. Engrs.* Feb. 8, 1915, p. 332

High speed steel also owes its existence partly to Hadfield's research work.

It was not surprising then, that it was Hadfield who should help solve the difficulty of the electrical engineers in their development of the transformer, due to the poor magnetic quality of the iron then available. With his usual desire for thoroughness he associated with him Professor Barrett of the University of Dublin, who was an expert in the field of electro-magnetism. Between 1895 and 1900 they investigated the magnetic properties of all conceivable simple combinations of iron, with the available elements. A great many of these alloys were already available from Hadfield's investigations of the mechanical properties during the previous decade, but numerous others were prepared at this time. The results were published in 1900 and 1902[2]. While many interesting alloys were developed, only two appeared to be of commercial value, the ferro-aluminium and the ferrosilicon alloys. Both of these alloys showed greater permeability and lower hysteresis loss than the best Swedish charcoal iron. Furthermore, the electrical resistance of the four percent alloys was five times that of the unalloyed iron, thus decreasing eddy current losses to an almost negligible factor. On account of the greater ease with which the silicon alloys could be made, efforts were concentrated on these rather than on the aluminium alloys. Four percent silicon-steel was prepared and rolled into sheets, 20 mils thick, and tests of these gave a permeability about 25 percent higher than that of the Swedish iron (μ max = 3600), a hysteresis loss of about two-thirds that of the pure iron (1.7 watts per kg. at 60 cycles = 2100 ergs per c.c. per cycle for B = 10 000), and an electrical resistance five times that of the pure iron (about 60 microhms per c.c.). Furthermore, and this was just as important, the aging was nil.

The first transformer using this new material, called "Stalloy", was built in 1903, and weighed 30 pounds. This was followed by a 40 kw and a 60 kw transformer that have been in constant service ever since. The original core loss of the former was 176 watts, and this was decreased to 131 watts after seven years service. Its weight was 830 pounds instead of 1120 pounds for a transformer of the same capacity made from "Lowhys" iron. It was estimated that during those seven years the transformer had saved the company using its 8700 kw-hours or $117.50 (with power at 1.3 cents per kw-hr.). Another illustration showing the possibility of reducing the weight, and thereby the cost of transformers is found in the case of a 60 kw transformer that could be put into a 40 kw tank.

Hadfields first patent application was filed in the United States on June 12, 1903 and the patent was granted December 1, 1903[3]. This patent, therefore, expired quite recently.

Considering the introduction of silicon-steel in this country, while the first transformer using silicon-steel in England was built in 1903, it was three years before the news had reacted upon the minds of the manufacturers in this country sufficiently to lead to action. The steel was recognized as revolutionary in its effect upon the characteristics of the transformer, it was talked about and written about, and its use urged by those in position to know, but adoption required financial investment, change of designs and change in methods of manufacture, all of which had to be carefully considered before the manufacturer could feel warranted in taking the step. Finally in the early part of 1906 the reaction took place with such force that before the year was half gone, not only was silicon-steel made in this country but the first transformers were on the market. The steel companies associated with the large electrical manufacturers obtained licenses to make silicon-steel under the Hadfield patent, but the license to make the steel did not carry with it a disclosure of the process of manufacture, and consequently it was necessary for each steel mill to develop its own process.

The large electrical manufacturers were actively interested in this development and intensive work was carried on in the spring of 1906. Many were the failures, and the quantity of expensive steel sent to the scrap heap was measured in hundreds of tons. But in spite of all kinds of mishaps the work progressed and at the end of three months of intensive work the first sheets of four percent silicon-steel were ready for the transformer. Since that time America, and all the world for that matter, has paid tribute to Hadfield both in the form of recognition and license.

In 1910 Dr. Morton C. Lloyd of the Bureau of Standards at Washington in a paper before the Franklin Institute, Philadelphia, estimated that at that time silicon-steel was saving the United Sates something like ten million dollars worth of electrical energy annually. What the total saving to the world has been during the 17 years that the patent has been in force it is difficult to even guess, but taking the above figure as an average for the United States and doubling it for the world as a whole, we get as a conservative total for the world for 17 years the sum of 340 million dollars, nearly enough to build the Panama Canal.

Since the introduction of silicon-steel a great deal of investigational work has been done to obtain even better magnetic materials. The work of Gumlich[4] extending over two decades, deserves especial mention. He was largely instrumental in introducing silicon-steel in Germany.[5] Burgess and Aston[6] of the University of Wisconsin investigated a large number of iron alloys using electrolytic iron as a base. They found that

2 Barrett, Brown & Hadfield: Conductivity & Magnetic Properties of Iron Alloys.
Proc. Royal Dublin Society 7, pp 67-126, Jan. 1900
Trans. Royal Dublin Society 8, pp. 1-22, Sept.1902
Jour. Inst. Elect. Engrs. 31, pp 674-721, Apr. 1902

3 U. S. Patent No. 745 829.

silicon, arsenic and tin improved the magnetic properties, but that other elements, like copper, manganese, antimony and nickel decrease the magnetic properties. A few of the other investigators are Baker[7] in England, Paglianti[8] in France, Hunter[9] at Rensselaer Polytechnic Institute and Honda in Japan. In spite of all this work, however, silicon-steel is used today exclusively for transformers and is coming into use more and more extensively even for motors, and generators. Manufacturing processes have been improved and modified, and better raw materials are obtainable now than 17 years ago, as a result of which the energy losses of present day four percent silicon-steel are only slightly in excess of one watt per kg. instead of two watts per kg. as obtained by Hadfield in 1903, and the permeability is 8000 instead of 3600.

That there is still room for improvement is shown by the results of the investigations that it was the author's privilege to direct at the University of Illinois between 1912 and 1916,[10] and by the further investigations that have been made at the Westinghouse Research Laboratory since 1916. By refined methods of preparation and subsequent heat treatments by the use of vacuum, ferrosilicon alloys have been produced that have a maximum permeability of 40 000 or more (instead of 8000) and a hysteresis loss of 300 ergs per c.c. per cycle for $B = 10\,000$ (instead of 1500 ergs). Ways and means have also been found of so treating commercial silicon-steel in bar form as to impart to it these superior properties. This treatment consists of removing the carbon (about 0.05 percent) from the commercial steel to a point well below 0.01 percent by annealing under oxidizing conditions. Patents have been granted both on the product having the superior magnetic properties,[11] mentioned above, and on the method of discarbonizing the commercial steel.[12]

MATERIAL FOR HIGH FLUX DENSITIES

Thus far magnetic materials for transformers have been considered, for the reason that this is the only commercial apparatus in which a high grade magnetic material is of sufficient value to warrant the cost. There are, however, certain parts of dynamo machinery in which improvements in the characteristics of present day material would be highly appreciated, such as armature teeth and pole tips in which the magnetic induction runs very high and imposes a lower limit upon the amount of material used. Low hysteresis loss and high maximum permeability are of secondary importance in this case. What is needed is a material having high permeability at high flux densities. The best material available today is the purest commercial iron, iron as free from oxide and other impurities as possible. It was thought for a long time that no other material had a higher saturation value than pure iron, and it was not until Dr. P. Weiss[13] of Zurich in 1912 showed that an alloy of the composition Fe_2 Co has a saturation value ten percent higher, that scientists changed their minds. The FeCo alloys have since been further investigated, confirming Dr. Weiss' results, and data were obtained of permeability and hysteresis loss for alloys containing from zero to 34.5 percent cobalt, showing that the latter would be admirably suited for armature punchings. However, there is one serious drawback. The alloy, at the present prices of cobalt, would cost between 50c and $1.00 per pound, which is prohibitive, and it is doubtful whether the cost will ever come down to a point where it can be generally used. The third element in the same class with iron and cobalt, namely nickel, lowers the ultimate saturation value, but it has been found that a nickel content of 5 to 7 percent raises the permeability for high inductions by about five percent, and this alloy may therefore come into use to a limited extent.

PERMANENT MAGNET MATERIAL

In the field of permanent magnets there has been a great deal of new development in late years[14]. High carbon steel (1 to 1.5 percent C) was used until the discovery of tungsten steel about 1910, containing five to six percent tungsten and one-half percent carbon. The war brought about a tungsten famine and chromium was substituted with partial success. Fortunately, new sources of tungsten were found and tungsten steel has been used ever since. However, a new steel has been discovered recently containing for the best results 35 percent Co, 7 to 9 percent W or Mo and 0.5 percent C. It may or may not contain Cr. This steel is very hard and difficult to work but is such an improvement upon the previous steels that it may, in spite of this disadvantage, succeed in conquering the field. It is peculiar in that it must be quenched at 1100 degrees and must be initially magnetized in a very strong field ($H = 500$ or more) before the advantage over tungsten steel appears. But once so treated it has a coercive force of 200 gilberts as compared to 70 for tungsten steel and 40 for carbon steel.[15].

4 *E.T.Z.*, June 26, July 3, 10, 17, 1919.
5 *E.T.Z.*, 22, p. 691, 1901.
6 *Met. & Chem. Eng.* 1910.
7 *J. Iron & Steel Inst.* 64, p. 312, 1903. *J. Inst. Elect. Engrs.* 34, p. 498, 1904-5
8 *Metallurgie* 9, p. 217, 1912.
9 *Am. Electrochem. Soc.* Apr. 8-10, 1920.
10 Bulletins Nos. 72, 77, 83 and 95 of the Eng. Exp. station, Univ. of Ill.
11 U. S. Patents 1,277,523 and 1,277,524, Sept. 3, 1918.
12 U. S. Patent 1,358,810, Nov. 16, 1920.

13 Comptes Rendus, 156 p. 1970, 1913.
14 S. P. Thompson: Steel for Permanent Magnets. *Jour. Inst of Elect. Engrs.* 50, p. 80, 1913.
15 Patents have recently been granted to Dr. K. Honda of Japan for his steel, U. S. Patents 1,338,132,—133, and—134, but it is understood that the invention may have been anticipated by investigators in this country.

Arc Welding Equipment in the Foundry

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ELECTRIC arc welding apparatus is rapidly becoming an essential part of modern foundry equipment. The work which can be performed by the arc welding process may be classified into three general classes:-

1—Cutting of heavy risers and sink heads, from steel or iron castings.
2—Repairing castings, such as the filling of blow holes or building up parts omitted from the original casting.
3—Repairing foundry equipment.

Each of the above requires different treatment, although the same type of welding equipment may be used for all classes of work.

The function of the arc welding equipment referred to in this article is to supply direct-current having a voltage characteristic suitable for welding. The complete equipment includes the necessary control, electrode holders, operator's helmets and face shields.

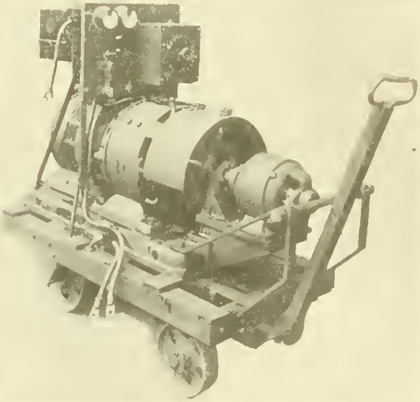

FIG. 1—SINGLE-OPERATOR WELDING EQUIPMENT
Current range 50 to 225 amperes.

Motor-generator sets having sufficient capacity to supply current for carbon electrode work, may be provided with control panels giving current regulation for heavy carbon electrode work, or for metallic electrode work. The high current capacity sets have become known as multiple-operator equipments, because they can be used by several operators, working independently. Multiple-operator equipments are built in capacities varying from 300 to 1000 amperes. Machines having a capacity larger than 1000 amperes have been built, but it is usually found that the 1000 ampere set has ample capacity for use in large installations. The single-operator unit has a capacity sufficient for one welder only, working with a metallic electrode, over a range of from 50 to 225 amperes.

A single-operator welding equipment of the portable type is shown in Fig. 1. This machine supplies current varying from 50 to 225 amperes for metallic electrode welding and 150 amperes maximum for carbon electrode welding. If several of these machines are available, they may be paralleled to obtain higher current values for both welding and cutting.

A 1000 ampere welding equipment installed in a modern foundry is shown in Fig. 2. This equipment, in combination with the proper control panels, will supply current for a number of operators working independently for metallic electrode welding, or higher current for carbon electrode welding or cutting. The range of current adjustment necessary for either class of work may be obtained from the same control panel. A control combination frequently used for multiple-operator sets is shown in Fig. 3. The large panel on

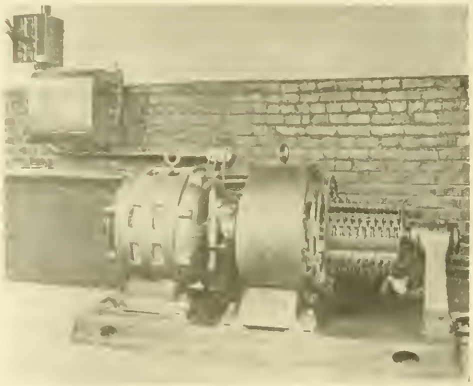

FIG. 2—MULTIPLE-OPERATOR WELDING EQUIPMENT
Current capacity 1000 amperes.

the left controls the generator and provides for current adjustment from 250 to 750 amperes for carbon electrode work. The small panel on the right is an outlet panel for metallic electrode work. One or more of these panels can be used with the multiple-operator set. The portable outlet panel, Fig. 4, is also frequently used with the multiple operator equipment.

The single-operator sets are designed so that no power is dissipated in stabilizing resistance connected in series with the arc circuit. Such a set, therefore, operates at a much higher efficiency than the multiple-operator sets which require a stabilizing resistance in each arc circuit. If the electrical efficiency was the only question involved, the choice of type of equipment would be simple. However there are other factors that

have a direct bearing on the choice of equipment namely:—

1—The first cost of the welding equipment.
2—The cost of installation.
3—The ratio of carbon electrode jobs to metallic electrode jobs.
4—The floor space available.

The first cost of a number of single operator machines will be considerably more than the cost of one

FIG. 3—GENERATOR CONTROL WITH OUTLET PANEL
For use with multiple-operator equipment.

multiple-operator machine for the same total capacity. The distribution cost of the primary source of current supply will usually be less than the distribution of current at arc welding voltage, as less copper will be required. If the cost of power is high, the saving in operating expense obtained by using the single-operator unit may off-set the higher first cost of the single-operator units.

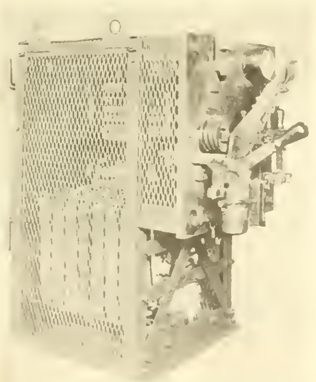

FIG. 4—PORTABLE OUTLET PANEL
For use with multiple-operator equipment

The ratio of carbon electrode work to metallic electrode work will influence the choice of equipment for, although the single operator units may be operated in parallel to obtain high currents, the ratio of jobs may be such that single-operator units will not be available for parallel operation, when required. Floor space may not be available for assembling several single-operator units for parallel operation, in which case, one multiple-operator unit must be used. A combination of the two types of equipment, in many cases, makes a more efficient and flexible installation.

FIG. 5—CUTTING RISERS FROM STEEL CASTINGS WITH THE CARBON ARC

Risers and sink heads are cut from the castings, to best advantage, by using high current and the carbon arc, but repairs to castings or foundry equipment are usually better when made with the metallic electrode, using current values varying from 150 to 200 amperes.

Fig. 5 shows a heavy job of cutting with the carbon electrode. The rate of cutting depends upon the current values used, and it is good practice to use approximately 500 to 650 amperes maximum, with a one inch carbon electrode. With this current about five minutes would be required to cut through a steel or cast

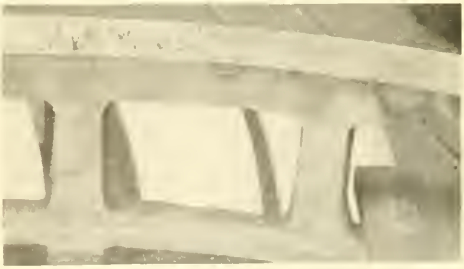

FIG. 6—REPAIRS MADE TO STEEL CASTINGS WITH A METALLIC ELECTRODE

iron block four in. by four in. Approximately the same length of time would be required to cut through a circular cross section of iron of five in. diameter. Work of this nature is best performed by means of high current machines. If single-operator machines were used, three or four of them, operating in parallel, would be required, each machine delivering its share of the load

as determined by the setting of the current-control rheostats.

Castings frequently have defects, such as blow holes, that can readily be repaired by means of the electric arc. Blow holes are easily filled by first cleaning

FIG. 7—METAL DEPOSITED ON CLOSE GRAINED CAST IRON WITH A METALLIC ELECTRODE

the casting thoroughly and then filling with metal deposited by the metal electrode. If the defective part of the casting is large, the cleaning can be done quickly by melting away the spongy material by means of the carbon arc, using current values from 300 to 500 amperes, or even larger, if there is a large amount of defective metal to be removed. The filling of small blow holes in a casting with the metallic electrode is shown in Fig. 6.

The practice of repairing just described applies

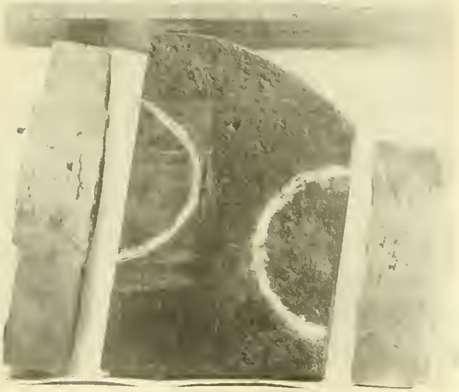

FIG. 8—METAL DEPOSITED ON CAST IRON

With either a large diameter metallic electrode or by a carbon electrode, using iron filler rods.

principally to steel castings. The welding problems encountered in cast iron work are more complex. It is difficult to obtain a soft weld on cast iron, due to the formation of a layer of hard metal, apparently a high carbon steel, in the zone of fusion between the parent casting and the deposited material. This zone of hard metal can be diffused and entirely eliminated by properly annealing the casting. Large castings of gray cast iron are usually of a coarse grain structure and it is difficult to obtain good fusion between the casting and the deposited metal. Pre-heating and subsequent annealing are advisable in many cases in order to obtain good results in welding cast iron.

FIG. 9—METHOD OF STUDDING CAST IRON TO INCREASE STRENGTHS OF WELD

Fig. 7 illustrates the method of building up a pad on cast iron by depositing metal by the metallic electrode, and the filling of a hole which was later drilled. The hole was drilled through the deposited metal only, so that the hard zone referred to was not encountered. The deposited material shown in section could easily be machined except at the zone of fusion between the deposited metal and the parent casting.

Filling work which was done with a large metallic electrode, using high current values, is shown in Fig. 8. The section at the four inch line of the rule was filled with ⅜ in. Norway iron, used as a metallic electrode.

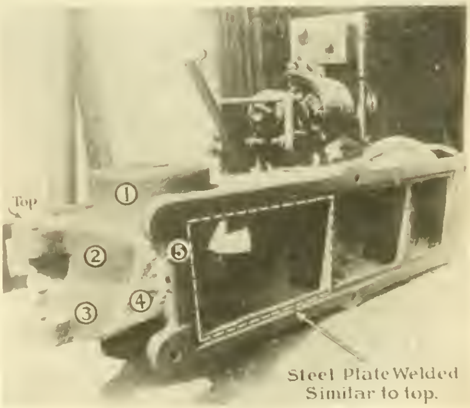

FIG. 10—REPAIRS MADE TO THE BODY CASTING OF ARC AIR COMPRESSOR

The slag inclusions, appearing as dark spots in the deposit, are to be expected in using this iron as a metallic electrode. The section under the 13 in. mark on the rule was filled by using the carbon electrode and the same grade of Norway iron as a filler material. Although such work may be done rapidly, slag

inclusions are to be expected when the average operator deposits the iron in this way. The slower method, using a smaller metallic electrode will result in a deposit similar to that shown in Fig. 7.

A method frequently used in repairing heavy cast iron castings is shown in Fig. 9. The metal of such castings is usually coarse grained and it is very difficult to get good fusion between the cast iron and the deposited metal. The break is "V-ed" out, and holes are drilled and tapped for receiving steel studs. The cross-section of the weld shows how the studs act as anchors for the deposited metal. Some interesting and valuable repair work has been done by using this method.

Fig. 10 illustrates the successful repair of a broken casting without studding. The main body casting of a large compressor was broken into five separate pieces when the connecting rod of the compressor became disconnected. The parts to be welded formed the crank case, which had to be oil tight, so that it was necessary to make a weld which would not leak oil and which would be sufficiently strong to withstand the vibration of the compressor. There were five complete fractures intersecting each other at five points within a radius of eight inches so that in making this weld, careful work was required by the operator in order to avoid trouble from expansion and contraction strains. The walls of the casting were approximately one inch thick on flat surfaces and two inches thick at the ribs. The total length of the weld was 55 inches. The work was completed in a little less than six hours, including the time required to cut and prepare the steel plate (shown in the illustration) to do the welding, and to set up and align the repaired casting. The actual welding time was one hour and 45 minutes, with a power consumption of 12 kilowatt hours.

In this instance the result was not only a saving in the cost of a new casting but, of far greater importance, the machine was in service again within a short time, whereas several months would have been necessary to obtain a new casting and do the necessary machining.

The general statement can be made that, in regard to foundry products, made by supplying missing parts or filling blow holes in steel castings, do not result in an inferior product. It is admitted that a foundry which was 100 percent perfect would need no process for adding metal to castings already poured. However many discriminating users of foundry products after thorough investigations of the results obtained by electric welding, have approved its use. The prejudice which exists to a certain extent against "patched up" castings will disappear as knowledge of the welding processes and the results which are obtained through their use become more generally known.

Typical Relay Connections—III

LEWIS A. TERVEN

WHERE it is desirable to trip oil circuit breakers from the current transformers connected on the main line without the intervention of a separate source of tripping current, some device is necessary in order to use the standard overload relay of the induction type with its desirable features of inverse time element. The use of this direct series trip attachment is exemplified in Figs. 15 to 20 inclusive, the manner of operation being as follows: Referring to Fig. 15, the current from the secondary of the current transformer passes through the trip coil of the oil circuit breaker, through the primary coil of the direct trip attachment, and finally through the series coil of the overload relay. When the current exceeds the trip setting of the overload relay and the contacts of the latter close, a short-circuit will be put upon the secondary of the direct trip attachment. When the short-circuit is established in the secondary of this small auxiliary transformer, the pull exerted by the main coil of the direct trip attachment will be quite small, thus allowing the pull of the trip coil of the circuit breaker to take effect, causing the latter to operate.

With this type of auxiliary device, the current from the current transformer passes through the trip coils of the circuit breaker and in case of a severe short-circuit, if the current transformer is not operating near its point of saturation, the current flowing in the trip coil will be of sufficient magnitude to cause the circuit breaker to trip, irrespective of the condition of the overload relay. In order to avoid such a contingency an inductive shunt is sometimes used, connected in parallel

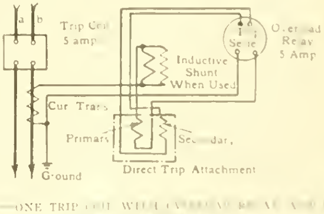

FIG. 15—ONE TRIP COIL WITH OVERLOAD RELAY AND DIRECT TRIP ATTACHMENT.

with the trip coil of the breaker. The object of this shunt is to divert a portion of the current from the trip coil so that the holding coil is strengthened at the expense of the tripping coil. Under these circumstances the holding coil will fulfill its function regardless of the current flowing in the secondary until the relay contacts may be closed, when tripping will occur according to the desired relay setting.

In Fig. 15 a single-phase circuit is shown with overload relay protection. However, reverse power protection can be secured in a similar manner, rendering it unnecessary to have a separate tripping source for circuit breakers provided with the direct trip attachment.

Figs. 16, 17 and 18 show the direct trip attachment as used with three-phase circuits, giving three different connections of the current transformers, while Figs. 19 and 20 show three-phase circuits protected by three overload relays using respectively three and two coils for tripping. As a rule only two trip coils, two relays, and two direct trip attachments are supplied, while with ungrounded systems two current transformers connected in V are considered sufficient. For grounded systems or for more thorough protection of the ungrounded system, three current transformers may be used connected in Z.

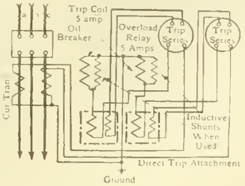

FIG. 16—TWO TRIP COILS AND TWO OVERLOAD RELAYS WITH DIRECT TRIP ATTACHMENT

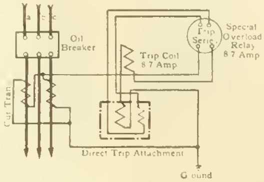

FIG. 17—ONE TRIP COIL AND OVERLOAD RELAY WITH DIRECT TRIP ATTACHMENT

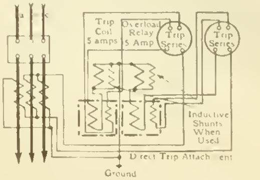

FIG. 18—TWO TRIP COILS AND TWO OVERLOAD RELAYS WITH DIRECT TRIP ATTACHMENT
The z connection of current transformers is used with a grounded neutral system

In order to protect electrical apparatus from internal defects caused by grounds or short circuits, relays of different characteristics may be used, the function being to balance the power on one side of the apparatus with that on the other side. Naturally the amount of power entering will correspond with the

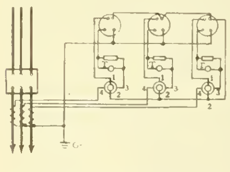

FIG. 19—THREE TRIPPING COILS AND THREE OVERLOAD RELAYS WITH THREE DIRECT TRIP ATTACHMENTS

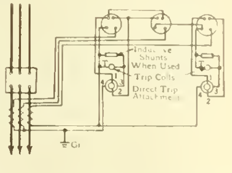

FIG. 20—TWO TRIPPING COILS AND THREE OVERLOAD RELAYS WITH TWO DIRECT TRIP ATTACHMENTS

amount leaving, neglecting the small internal losses of the apparatus. Fig. 21 shows the differential relay scheme arranged to protect a single-phase transformer.

As long as no internal current losses occur in the power transformers the current in the secondaries of the two current transformers will simply circulate without any of it passing through the overload type of relay which is connected in parallel with the transformer secondary. Should a loss of current occur in the power transformer, the difference between the entering and leaving current, as shown by the current transformer, will flow through the differential relay, causing it to operate and trip both of the circuit breakers, thus isolating the apparatus which is to be protected. In this connection an auxiliary circuit closing multicontact relay is shown which operates to trip both of the circuit breakers without having their trip coils connected in parallel, as would be the case if it or similar means were not employed.

In order to avoid the cost of high-potential current transformers, the scheme of connections shown in Fig. 22 may be used for overload protection. The only high-tension equipment consists of a single high-tension bus support upon which is mounted a small slate panel which contains the low-tension current transformer and the two relays shown in the diagram. The current from the secondary of the current transformer passes through the overload relays and through two coils upon the transfer relay. When the current reaches the value corresponding to the relay setting the overload relay will close its contacts, thereby short-circuiting a shading coil which will nullify the effect of the lower coil of the transfer relay and cause the upper coil to attract the plunger of the

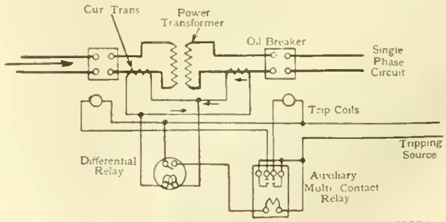

FIG. 21—DIFFERENTIAL RELAY ARRANGED TO PROTECT TRANSFORMER

transfer relay, pulling with it a micarta chain. The latter serves to actuate a small knife switch at its lower extremity while at the same time preserving the insulation of the high potential circuit to ground. The tripping circuit is connected through the knife switch to the circuit breaker.

The same type of transfer relay in a slightly modified form is shown in Fig. 24, the object being to supply tripping power to circuit breakers where no auxiliary supply of current is available. As in the case of Fig.

22 the current from the current transformers normally circulates through the overload relay and through the two coils in the transfer relays. These two coils, being wound on separate electro-magnets, have their actions mutually opposed upon the plunger of the transfer relay. When the contacts of an overload relay close, they

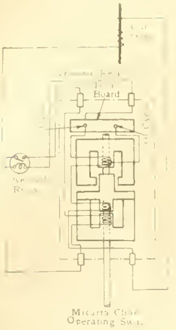

FIG. 22 HIGH-TENSION OVERLOAD RELAY PANEL

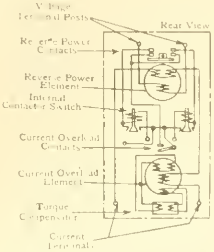

FIG. 23—INTERNAL CONNECTIONS OF REVERSE POWER RELAY WITH DOUBLE TRIP CIRCUIT

short circuit the coil wound upon the lower electro-magnet which eliminates the pull of the lower coil of the transfer relay, which is connected in series with the overload relay, and permits the plunger of the transfer relay to be drawn up. This operates the small switch within the relay, whose two positions are clearly indicated in the wiring diagram. In normal operation the current passes from the current transformer, through the overload relay to *b* and *c* in the switch of the trans-

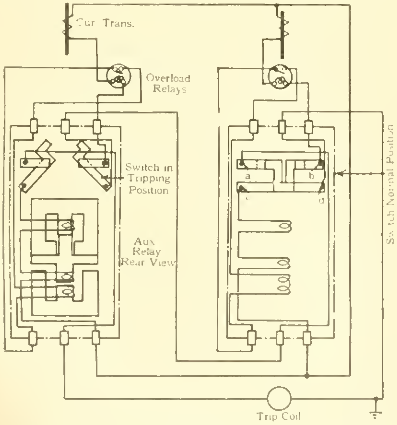

FIG. 24—CONNECTIONS OF AUXILIARY RELAY FOR ALTERNATING-CURRENT TRIPPING

Connections shown are as viewed from the rear of the apparatus.

fer relay, through the two coils of the latter and back to the secondary of the current transformer as shown at the right. After the overload relay has caused the transfer relay on the left to assume the tripping position, the current from the current transformer will pass through the overload relay, through one side of the switch, then from *a* to *d* of the second transfer relay, and though the trip coil of the circuit breaker back to the first relay, through its auxiliary switch and its two series coils to the other side of the current transformer.

The scheme as shown can be used for reverse power relays and the same combination may be used in a general way as is shown for the direct trip attachment for oil circuit breakers as shown in Figs. 15 to 20. However, more positive action is secured with connections shown in Fig. 24 as normally no current flows through the trip coil of the circuit breaker and there is no liability of tripping the breaker under short-circuit conditions as occurs with the direct trip attachment where current from the current transformer always flows through the trip coil of the circuit breaker.

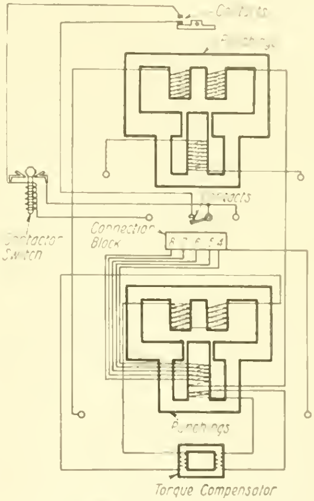

FIG. 25 REVERSE POWER RELAY
Internal connections viewed from rear of relay

Some kinds of relays depend for their function upon the relative directions and values of the current and the voltage in the electric circuit, such as reverse power relays. One type of this kind of relay is illustrated in Figs. 23 and 25. The relay shown consists of two elements; the first being a standard induction type overload relay complete with contacts, and the second consisting of current and voltage coils so placed as to constitute a wattmeter element. The second element is likewise provided with relay contacts and these close whenever the direction of power is reversed from the direction for which the relay is set. As the two sets of relay contacts are connected in series, no trip circuit will be established unless an overload is present and a reversal of current, occurs at the same time. Furthermore, an inverse time setting is provided for the overload element, so that surges incident to switching or synchronizing will not trip the breakers due to the

closing of the relay contacts. An additional and distinct setting is made for the amount of current required to operate the overload element as may be seen by referring to Fig. 25, current taps *4*, *5*, *6*, *7* and *8* amperes.

In order to be able to respond to very low torque, as occurs when the system voltage is low, the relay contacts are quite light, and for that reason an auxiliary or contactor switch is provided inside of the relay, so that the current for tripping purposes will pass through the main contacts of the contactor switch, the latter being locked in by its own current until the breaker trips. This latter feature of the contactor switch, as well as its design, renders an auxiliary or pallet switch necessary at the circuit breaker in order to interrupt the trip circuit.

Some Labor Conditions in Foreign Countries

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THE increasing interest in foreign business has brought a desire for all information possible on the conditions of labor and labor costs which differ from those in the United States. This article will be confined to four countries where the writer has had extensive experience; namely, Norway, Japan, Mexico and Chile. The remarks referring to Norway may be taken in a general way as applying to Denmark and Sweden. The conditions in Japan also apply in a broad general way in China, but costs in China are slightly less than in Japan. Mexican conditions apply in Central America also, and those in Chile are quite characteristic of South America.

The labor rates as given apply in most cases to conditions before the war. My work in Japan was in part during the first year of the war, but prices given are prewar prices. In South America the work was since the war. The great probability, we may assume is, that labor costs in all countries, will revert to approximately prewar values in a very few years. In all these countries, however, conditions have departed less from normal than in the United States. In general it may be assumed for all foreign work that, while a day's work for a mechanic or a day laborer costs much less per day than in the United States, the output is less and in every way the efficiency is lower.

NORWAY

Of the labor in the four countries mentioned, that in Norway is the most efficient, and most nearly corresponds to our own labor conditions. In 1912 I was able to obtain average good mechanics in Norway, on work of erection, at from six to eight crowns per day of nine hours. Common labor at the time was four to five crowns. The crown at normal exchange equals 26.8 cents. Station operators on eight hour shifts received 130 to 150 crowns or say $40 per month. Lady stenographers in offices in Christiania, who could take dictation in English, German or Norwegian, received 100 crowns or $26.80 per month. In output of work per day, I would consider labor as ranking about 75 percent in comparison with labor in the United States. This percentage will vary somewhat with different classes of labor. While the output is less and the labor is slow the work is usually well done and reliable. I found the workmen easy to get along with, honest and capable of taking interest in the work. Methods of work are rather formal, unnecessary attention being given to mere details which are not vital to the results desired. As Norway is considered as the country having the greatest of all water power output per unit of population and, as this power is for the most part very favorably located and is being rapidly developed, it follows that a large element of labor is being educated in electrical work, and at present labor conditions are quite favorable for those called upon to do erection work in that country.

JAPAN

To the engineer who is lined up for a big job in the Land of the Rising Sun, the imaginary troubles at first thought may make the job seem rather hopeless. His troubles, however, will be along rather different lines probably than those that first occur to him. It probably is best, in going on any foreign work, not to form any opinions as to what the conditions will be, or what we will or must do. Start with an open mind and especially without any prejudices for or against what you are to meet. The engineer bound for Japan will naturally feel he will be much handicapped by not knowing the language. This will not be as much of a detriment to him as a failure to have a working knowledge of the language in many other countries. Many Japanese engineers have had training in England or in the United States and usually know our language well. Those whose training has taken place in the schools of their own country, usually know English quite well. While they naturally talk our language in a hesitating way, and chose their words slowly, they almost invariably use good English and express themselves correctly.

One will always have native engineers who can go into matters fully and can translate correctly any directions given. One will usually be taken care of well by the concern for whom the work is being done. This, of course, does not mean one will have food or surroundings entirely the same as he is accustomed to. But

with the native ways of service and native customs, which are naturally radically different from our own, one will be well provided for. At the Inawashiro plant, where the writer spent most of 1914 and 1915, there were four foreign engineers, one English, two German and myself. The local company built a ten room house and furnished it for our use. Each engineer had a private room, with a rest room, a dining room, kitchen and bath room and two living rooms for a Japanese family to cook and take care of the house. This family had previously been in the service of an American family, and the cooking and service were good.

The Japanese mechanic or laborer is not exactly at home in handling very large and heavy work. This is natural from his limited experience on this class of work. However in handling light work, and especially such work as can be done without cranes or tackle, and with only the most primitive tools, he is rather superior to other people. This refers to such work as unloading, putting in place, getting things ready for erection and any straight ahead work. It is much the best practice to let the workmen do this work according to their own particular way, so long as this is possible. One of the principal difficulties the foreign engineer will have with Japanese labor is getting the workman to do certain things in the particular way wanted, when this is necessary. The ordinary Japanese workman usually decides early on the job that he has a better way of doing things than your way. Therefore, for work that must come to a certain fixed standard and must be done in a certain way, it will be necessary to show the worker exactly how this should be done, then watch the work very closely and allow no departure from the methods shown. The workman will never fail in his ability to imitate exactly what you do, if he so chooses, but he will change the method to suit himself if he is given any opportunity to do so. No worker I have ever met can reproduce a piece of work with the exactness that a Japanese will do it, if necessary, but he will not do it your way if he can possibly avoid doing so.

Labor in Japan is slow and, while wages are low, the item, be it an article or a days work, costs about the same as in the United States in the end. This may seem strange or unreasonable to many considering the low labor rates, but the four foreign engineers at Inawashiro discussed this matter many times, and in about all its phases, and we came invariably to the conclusion that the other nations had little or nothing to fear from Japanese labor, when the cost of the finished product is considered. The average mechanic, on the Inawashiro plant, was paid about one yen or a yen ten per day. Some specialists, a very few, received one and one-half or two yen, the par value of the yen being 49.8 cents or say fifty cents. Men at common labor received about sixty sen or thirty cents, the sen being equal to one-half cent. However, more than half of the common labor about the construction of the Inawashiro power house, a building about eighty by one hundred and [illegible] feet, by seventy five feet high, was furnished by women and girls collected from the small villages about the district. The power house was a steel frame building, filled in with brick and cement. Every brick and hod of mortar or sand was carried up on this building by women and girls. All [illegible] of machinery and polishing of parts, the moving of freight cars and similar work was done by women and girls, and all fuel and provisions were brought in on their backs. For this labor they received an average of thirty sen or fifteen cents per day. They were very glad to receive this, as it was nearly twice as much as could be earned in the rice fields which represented their normal employment, and was much cleaner work and more healthful. Station operators in the larger and better plants received the equivalent of ten to fifteen dollars per month, and in some of the smaller plants as low as five dollars per month. Many small plants are in charge of women at merely nominal wages. While the Japanese will not resent incivility and lack of formality in an equal degree with the Spanish American, formal ways and methods probably count for more in the actual Japanese life than in other countries, and formal methods and rather extreme politeness will meet with much consideration from those, one is doing business with. A considerable degree of firmness in a duly formal and polite way will probably bring the best results on most occasions.

MEXICO

A great electrical development had taken place in Mexico and was being carried out during the last years of Diaz, as President of the Republic. But little has been done since and many of the larger as well as the smaller plants in the country have been wrecked and put out of service during the insurrection. Having been in Mexico during Diaz' time and again in 1916, the contrasted conditions were painfully apparent to me. As the superintendent of the big Pearson, 110 000 volt plant at Orizaba told me regarding the company's similar plant at Pueblo—"I have not seen it for two years. It has been out of service, and when the insurgents wanted some wire or a shaft or pulley or other item they went into the plant and took what they wanted from the machines, governors, etc. When a peon wanted some sole leather for his zapotos he went in and cut it out of a belt."

While I was at Orizaba, the employees of the city railways of the City of Mexico went on strike. While on strike the government drafted these men and sent them to the training camps at Orizaba. They brought with them all the controller handles and many of the motor brushholders and destroyed these parts at Orizaba. Such impulsive and irresponsible acts are rather characteristic of organized labor in Mexico, and are liable to make conditions uncertain and expensive. It is a relatively common thing to leave work at night with apparently the happiest of understanding existing,

and have a strike before work starts in the morning. The interminable "fiesta" or holiday, can usually be reckoned on as due once or twice a week. This, however, is not so bad, as you know it is due as a custom of the country.

As in all Spanish speaking countries it is not advisable for an engineer personally to do any more real physical work about his plant than may be absolutely necessary. If he does he will lose caste with both the management and labor itself. A man in Mexico will work to very much greater advantage if he has a slight knowledge of the language, and even for one going down there for a single trip, it would be well to purchase a book or dictionary giving common words and expressions. It will not be found difficult to pick up enough of the language to make life go smoother and help things along very much. Common labor was at a rate of fifty to seventy cents per day and mechanics about twice that rate. An engineer in charge of erection will find he must watch the work closely as it goes along, on account of the most unexpected things being done by the workman. Patience will be a necessary virtue. Politeness and consideration will take one far in all Spanish speaking countries.

CHILE

Somewhat similar methods as to labor and working conditions exist in all the Latin American countries, but I think labor in general will be found more intelligent and better in an all around way in Chile than in Mexico. The Chileno has been spoken of as the Yankee of South America. While the comparison thus implied may not be very apparent, still there are some reasons for the expression. Wages vary greatly throughout the country. While agricultural labor probably represents the greatest labor element, mining and the nitrate interests are big employers of common labor. Wages may vary from a peso, usually about 20 cents, per day on the big estates to as much as six or eight pesos for similar unskilled labor at the mines. Some mechanics of the better class at the mines get as much as twelve to fifteen pesos per day. In connection with the above rates it should be noted that the agricultural laborer has his living practically free, while the mine worker has not. At the more important mines virtually all superintendents, foremen and head operators are American or English. On work consisting of rebuilding a number of large transformers for one of the mining companies, the writer paid his labor six to eight pesos per day of nine hours. These men were rather above the average in intelligence and reliability. The Chileno laborer is less impulsive than the Mexican and has relatively few holidays to keep him from his work. His standard of living is higher, and in all ways he is more dependable. The same necessity will exist, however, in South America as in Mexico, for the engineer to watch closely the work as it goes on, largely because this class of work is entirely different from what the natives are used to, and equally due, perhaps, to a natural irresponsibility in the native character. The engineer must hold himself responsible for all work, much more than in the United States. On a day rate no effort will be made to hurry work. As they say in the country, there is no word or expression in Chileno Spanish for hurry. However, the native will work hard and faithfully on piece work, if given rates that will bring him in a little better daily return. I have increased output fifty percent by giving a rate on piece work that enabled the operator to make eight pesos per day in place of six or seven.

While labor, in the class of work an electrical engineer wants done, is not efficient from our point of view in most of these countries, still one must consider matters from an entirely different view point than in the United States. This is particularly true in the Spanish speaking countries, and I think most right minded men will come to feel a sympathy for and an appreciation of some of the good qualities found in the poor peon or roto of the southern countries. He is ignorant and lacks energy and initiative, but the work we put up to him is so entirely different from anything his previous life has shown him that he cannot be expected to adapt himself quickly to new conditions. Owing to the class feeling in these countries he has always been looked down upon and treated as a dependent and an inferior. My own experience has been that some little consideration for these men, and an appreciation of their efforts, has had a remarkable resultant effect on their work and faithfulness.

In the United States, we are a rather brusque and direct acting people. While we perhaps take a very just pride in our ability to accomplish results, and in our ways of doing so at home, in going to foreign countries we sometimes fail to appreciate the fact that long experience and well established customs in these countries cannot be changed, and our own methods of doing things are not best away from home. It is not advisable to try to drive matters in the Spanish speaking countries, but rather to keep in line with established methods. Formality and extreme politeness are universal and must be observed. Even in dealing with common labor, politeness and consideration will take one very far. You will seldom find a workman or laborer who will not meet your efforts in this direction with an equal return, and they very much appreciate any sincere consideration on your part of their work. Don't be familiar but be sincere, considerate and polite. This may seem a common-place, but a real showing of these qualities counts for much more in these countries than with us. We want to live down the name of "Calibans" or "savages", which is frequently applied to us, and which has, to a considerable extent, been justified by the actions of some of our countrymen.

THE ELECTRIC JOURNAL

OPERATING DATA
FOR CONVERTING SUBSTATIONS

MARCH 1921

Commutator Maintenance of Synchronous Converters*

The creditable performance of a large synchronous converter is as much dependent upon the condition of the commutator as upon any other one item. It should also be borne in mind that a commutator only becomes thoroughly "seasoned", (the insulation baked out and all parts in their final set position) after operating in service for a considerable time, followed by some tightening and grinding. Owing to lack of facilities for heavy current loading at the works, it is not feasible, in all cases, to completely season large commutators before shipment. It should be expected, therefore, that a certain amount of tightening and grinding will need to be done after the converter is put in service, particularly if the commutator is of large size. The importance of having the maintenance and repair work on commutators done always under the direct supervision of experienced mechanics should not be overlooked.

FIG. 1—GRINDING DEVICE FOR TRUING COMMUTATORS

The indication that the commutator needs attention will usually be manifested by a general unevenness or roughness caused by high or low bars. It is seldom that trouble is occasioned by flat spots or eccentricity. However, if these conditions are not corrected in the early days of their development, poor commutation is inevitable, causing overheating of the commutators and rapid deterioration of the brushes, clips and pigtails; and the ability of the machine to handle overloads will be greatly impaired.

In exceptionally bad cases, where flat spots exist, or there is eccentricity, it may be necessary to use a turning tool, but for ordinary cases a grinding tool, Fig. 1, is preferable and is recommended. Commutators should always be ground at full normal speed. In cases where converters are motor started, the starting motor can readily be utilized for grinding. Care should be taken, however, to see that starting motor windings do not overheat, as starting motors are only designed for short time service and their continued operation, for commutator grinding, must be with caution in this respect.

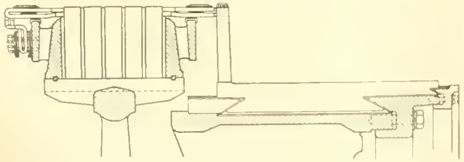


FIG. 2—SECTION OF COMMUTATOR SHOWING AUXILIARY V-RING

On self-starting converters, a shaft extension is provided on the alternating-current end for mounting a pulley to drive the rotor for grinding, and where possible to do so, it is preferable to grind by this procedure. Where it is not feasible to mount a pulley for separate drive grinding, the rotor can be driven at synchronous speed from the starting taps on the transformer, if it is an alternating-current self-started unit, or on reduced direct-current voltage, if it be a direct-current started unit. Great care is, of course, necessary in grinding, when running a converter under its own power, due to the voltage bet[illegible] undesirable [illegible] ing to leave [illegible] brushes down [illegible] grinding by running from the direct-current side, is obv[illegible]

In cases where grinding [illegible] from the direct-current side, just as few [illegible] should be left down for carrying current [illegible] Ordinarily, half of the brushes on two adjacent [illegible] mits grinding half of the face of the commutator at a time, leaving the brushes down only on that part of the commutator where the stone is not working. All br[illegible] while grinding is being done in this manner should be thoroughly cleaned off before the machine is again put back in service, as some copper and stone dust is sure to [illegible] in the face of the brushes. This will not only cause rapid wear of the brushes themselves, if it is not cleaned out, but will also scratch and otherwise damage the commutator and [illegible] commutation. In grinding the commutator when running from the direct-current side, it is well to provide some sort of an insulated platform for the operator. In case it is found necessary to mount the grinding tool on the positive arm of a machine having the negative grounded, it is also desirable to arrange for insulating the tool, as an extra precaution for protection to the operator. The danger of dragging copper across bars and short circuiting them should also be given consideration, when grinding is being done by driving from the [illegible] current side with appreciable voltages existing across [illegible] bars.

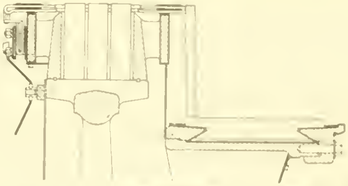


FIG. 3—SECTION OF COMMUTATOR SHOWING V-RINGS

Turning a commutator requires a much lower speed than for grinding. The speed for turning should not exceed 150 [illegible] per minute.

Before grinding a commutator, the machine should have been in service a sufficient length of time to bring the temperature of the commutator up to a constant value of at least [illegible] degrees C. The machine should then be shut down and the bolts holding the commutator V ring, shown in Fig. 2., should be tightened. This process of heating and tightening should be repeated until the commutator bolts cannot be tightened further, using a wrench that will not stretch the bolts. The proper leverage for use on commutators to insure tightness and still not injure the bolts is approximately as follows, assuming an average man['s] [illegible] 140 lbs. pull) at the end of the wrench:

Inches Diam of Bolts	Inches Wrench Length [illegible]
3/4	12
1	24
1 1/4	30
1 1/2	60

In tightening commutators having the double V construction, shown in Fig. [illegible], the outside or auxiliary V bolts should always be backed off slightly, say [illegible] half turn, before attempting to tighten [illegible] V. After the machine [illegible] given its [illegible] it should be run for at least 12 hours to reach a constant temperature on the commutator of at least 100 degrees C. before grinding. The commutator should [illegible] be ground down to a true surface.

*This is a companion article to the one by the author on "Commutator Brushes", in the JOURNAL for Feb. 21, p. 51.

It may be found, after finishing the grinding, that the undercutting has been so ground away as to leave sharp edges or burrs along the slotting. These sharp edges should always be bevelled off, and the undercutting thoroughly cleaned out before putting the machine in service again. To clean out the undercutting, any small stiff-bristled brush may be used. A brush with soft iron wire bristles will be found good for this purpose. In extreme cases the undercutting may have been entirely removed by the grinding, so as to leave spots where the mica will be flush with the copper. In such cases, the mica should be re-undercut to a depth of about 1/16 inch, and the edges bevelled and the slots cleaned out. The occasional brushing out of the commutator undercutting will be found very effective in maintaining good commutation, as well as prolonging the life of the brushes. The deposit in the slots from any graphite grade of brush always causes slight sparking, as well as some arcing and pitting on the brush face. These factors mean burning along the edge of the commutator bars, accompanied by extra rapid wear of the brushes.

In finishing off a commutator, emery cloth or paper should never be used on account of the continued abrasive action of the emery which becomes imbedded in the copper bars and brushes. Even when using sandpaper on a commutator, the brushes should always be raised, and the commutator wiped clean with a piece of canvas lubricated with a very small quantity of vaseline or oil. Cotton waste should never be used, and an excess of any kind of lubricant should always be avoided.

The armature winding should also be thoroughly protected during the time of grinding a commutator, to prevent accumulation of dirt and metal chips back under the commutator necks, which may result in an insulation failure when the machine is again put in service. This protection can usually be obtained by using a circular shield of fullerboard, or similar material, around the commutator at the end next to the armature, as shown in Fig. 1. This shield can easily be supported from the brushholders arms and should extend from the commutator surface to an inch or two above the surface of the armature. In turning off a commutator, it is always desirable to put a temporary canvas hood over the armature winding.

After grinding, the complete machine should be thoroughly cleaned by blowing out with dry compressed air, before replacing it in service.

R. H. Newton

The Journal Question Box

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1975—Chorded Windings—In Mr. Dudley's article of February, 1910, the following statement is made: "It is customary to wind the coil in slots so that it spans something less than full pole pitch." I would like to know why this is as it seems to me a unity value chord factor would be the most efficient. G.W.S. (CAL.)

It often happens that the number of series turns necessary for a given voltage of an induction motor is not desirable from the standpoint of the best arrangement of the conductors in the slot. In such a case, a larger number than actually required, but which gives the best arrangement of the conductors in the slot, is selected and the effective number of turns may be decreased to that required by the proper chording of the winding. The effective number of turns equals the actual number of turns times the sine of half of the number of electrical degrees spanned by the coil. The fact just mentioned makes the short pitch winding very convenient from the design standpoint. Short pitch windings increase very considerably the percent of the total length of the coil which is imbedded in the iron. This reduces the heating of the windings because the iron will conduct the heat away from the coils more readily than the surrounding air. Incidentally this type of winding results in a saving of copper and insulation. A sinusoidal wave form is the ideal for an induction motor. This can be obtained only approximately in practice, but decreasing the pitch shifts the layers of the windings through a certain angle from the full pitch position. Thus an overlapping of the current of the different phases is obtained which improves the flux distribution. E.E.

1976—Choke Coil—In connection with the type S lightning arresters on lines carrying up to 50 or 60 amperes, 2300 volts, we have been using home made choke coils, consisting of about 30 turns of No. 4 hard drawn weatherproof copper wire wound on a two inch pipe as a mandril. When suspended the coils are stretched to secure a small air-gap between the turns. Will you kindly critcise the practice. A.T.T. (ALBERTA)

Our criticism is that a coil with such a small diameter has almost a negligible inductance. It is a step in the right direction though. The inductance of a coil increases as the square of the diameter. G.C.D.

1977—Damping Windings—Will you please explain how the size of copper and its most efficient location is determined for putting in an amortiser winding on an alternator? Will you give an example showing how it would work out in a particular case? C.W.H. (N. J.)

The purpose of an amortissuer winding in a polyphase alternator is to damp out pulsations in angular velocity which arise from irregularities in the driving torque. Voltage is generated in the damper winding proportional to the amount of pulsation in velocity at which it occurs. With a given voltage the current and consequently the damping torque, depends upon the impedance of the damper winding. Since it is desirable to reduce the pulsations in velocity to a minimum the damper winding should have as low an impedance as possible. This means that a relatively large number of bars of large cross section should be used. Since the amount of pulsation in driving torque is a rather uncertain quantity to predict, and since the allowable variation in velocity is usually indefinite, the number and size of damper bars cannot be calculated with the same degree of accuracy as most of the other parts of the machine. Generators which are to be driven by gas engines or other prime movers having large torque variations require heavier dampers than those driven by prime movers with more nearly uniform torque, but in any case the actual design is based more upon judgment and experience with other machines than upon definite calculations. One general rule which applies to the spacing of the bars is that the distance between them should not be equal to the armature tooth pitch or any multiple of the stator tooth pitch. Usually a difference of 15 to 20 per cent between the rotor and stator tooth pitches is maintained. If the spacing of the damper bars coincides with the stator slot spacing, the generator may be unsatisfactory due to noise, increased losses or a poor wave form. Q.G.

1978—Meter Connections for Three-Phase Circuits—Where instruments are connected through current transformers on a three-phase system, what is the advantage in using a current transformer in each phase. I have been told this is to take care of unbalanced loads but I cannot see why two transformers will not do the same. R.H.L. (B. C.)

The third current transformer on a three-phase, three-wire system is only of advantage to help to carry the secondary instrument load; if only two transformers were used they might be overloaded. In a three-phase, four-wire system it is necessary to use three

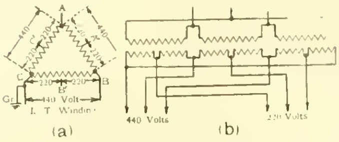
current transformers in order to measure the currents which might flow from any line to neutral or ground. The third transformer does not influence the effects of unbalanced loads on three-phase, three-wire circuits, which are properly metered with two current transformers. The connections employed for measuring various loads under all possible conditions in alternating current circuits have been thoroughly discussed by Mr. Group in a series of articles on "Switchboard Meter Connections for Alternating-Current Circuits" published in the JOURNAL for January to July 1920. The article describing in detail the connections for measuring any load under all possible conditions in a three-phase, three-wire circuit was published in the March issue. P.M.C.

1979 — LOW-VOLTAGE DIRECT-CURRENT GENERATORS—A 10 pole shunt wound commutating pole, 75-125 volts, 3600 ampere direct-current generator was connected to an electrolytic load consisting of a number of tanks in series. On a certain occasion a number of tanks were cut out and it should have only required about 20 volts to circulate the 3600 amperes. The above machine field rheostat was set for 20 volts and the machine connected across the tanks. Immediately the voltmeter and ammeter went over to full scale and the machine circuit breaker tripped out, it being set for 4500 amperes. Do you suppose that it was possible that the machine built up as a series generator, the commutating poles acting as a series field, in other words compounding, there being just enough shunt field to allow the machine to build up, after which the commutating pole overcame the shunt field. I am of the belief that the above machine when operated on the very low voltages would operate much better if the commutating poles were not energized. I would, therefore, propose short-circuiting them. R.H.L. (B.C.)

It is, of course, possible that the brushes are so set that the commutating pole flux is serving as useful flux for generating voltage. This would be due to the setting of the brushes. Moving the brush forward would decrease the voltage and moving the brushes backward would increase the voltage. The commutating poles should be energized at low voltage as well as high voltage. The remedy for the above trouble is to move the brushes forward a slight amount so as to avoid the compounding effect due to the commutating pole flux. D.H

1980—DELTA CONNECTED TRANSFORMERS—The high tension windings of three 200 kw. single-phase, 60 cycle, transformers are connected in delta for 13 200 volts, three-phase, and the low tension windings are connected in delta, feeding a 440 volt, three-phase circuit, and a tap is taken from the center of the low tension winding from each transformer as shown in Fig. (a), for a 220 volt , three-phase feeder. Both the 440 volt, and the 220 volt three-phase feeders, supply power for motors in the same plant, about 70 percent of the load being on the 440 volt feeder and about 30 percent on the 220 volt feeder. This system will operate satisfactorily when both sets of feeders are free. However, industrial plant distribution systems are very rarely, if ever, free from grounds. In Fig. (a), A, B and C represent the three 440 volt legs, while A', B' and C' represent the 220 volt legs, assuming leg C on the 440 volt system to be grounded, then what will be the potential from A' on the 220 volt system to ground? Please show in detail the method for determining what the maximum voltage will be from some leg on the 220 volt system to ground with conditions, as above stated. Is it not a fact that the 220 volt motors and apparatus will be subject to a strain of over 100 percent of normal voltage to ground, when a ground occurs on the 440 volt system. W. S. D. (TENN.)

Referring to Fig. (a), by drawing the equilateral triangle representing the voltage to some suitable scale, the voltage between any two points can be measured off. For instance, the potential between C and A' is the altitude of an equilateral triangle whose sides are 440 volts, its value is $\sqrt{(440)^2 - (220)^2} = 381$ volts. When C is grounded, A' is 381 volts above ground. This connection is not desirable because the

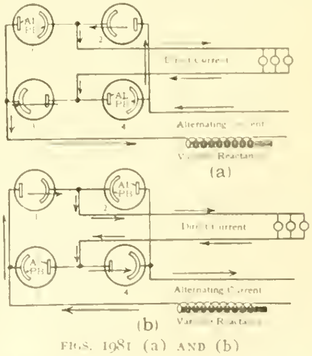


FIGS. 1980 (a) AND (b)

transformer is not being used economically. For instance, 350 kv-a, three-phase, at 220 volts will give full load on the secondaries of the bank, whereas if built for 220 volts, it would deliver 600 kv-a. J. F. P.

1981—NONDON VALVE—What are the essentials of a Nondon Valve? Explain the most suitable connection for general use? What is its efficiency and power factor? Why is the voltage reading across the direct-current circuit sometimes higher than the alternating line current? What are the troubles most generally encountered with the use of this valve and how are they overcome. G. C. Q.

The essentials of the Nondon valve consist of a metallic cathode of small surface, an anode of large surface and the electrolyte. The anode may be either of lead, polished steel or carbon; it is without influence upon the valve effect, if its relative surface is sufficiently large. The cathode must be of pure aluminum or an aluminum alloy with a very small proportion of other metals. The surface of the cathode must be relatively small because aluminum hydroxide forms on it which tends to prevent the current flow between the electrodes. A small cathode surface insures a more effective forming and breaking down of this surface resistor. The electrolyte is generally a concentrated solution of one of the following phosphate or sodium bicarbonate. Sodium bicarbonate has been found desirable to use, as the results are almost as good as obtained with the more expensive salts. Fig. (a) shows an arrangement of connections suitable for general use, employing four cells in order to rectify both halves of the current wave and also to increase radiation of heat generated. Arrows in Figs. (a) and (b) indicate the path of the current during each alternation. With the cells working properly, an efficiency between 65 and 75 percent may be obtained. A home-made rectifier will probably have an efficiency of about 50 percent. The power-factor is never above 90 percent, but is not necessarily low if the cells are operated at full-load. The most efficient method, for controlling the direct-current voltage, is placing a variable reactance in the alternating-current circuit as shown in Fig. (a). The Nondon valve acts both as a rectifier and a condenser. The capacity between the aluminum plate and the electrolyte is about one microfarad for every seventeen square inches immersed; the dielectric consisting of the thin film formed by the current action. When the current flows through the cell from the iron to the aluminum the amount of electricity stored is negligible due to the small resistance; however, when a reversal takes place a static charge is accumulated depending on the alternating-current voltage. When the current is flowing through cells 2 and 3 only, as shown in Fig. (a), cells 1 and 4 will be charged to the potential of the alternating e. m. f. On the next reversal the path of the current is as indicated by arrows in Fig. (b) so that static charge in cells 1 and 4 will tend to increase the flow of current through direct-current meter. This increase of flow only becomes appreciable when high resistance voltmeter is connected across the direct-current terminals. When a Nondon valve, having the proper value of capacity, is connected across an alternating-current supply, in series with a reactance coil, they will form a resonant circuit and the voltage reading across the alternating-current valve terminals will be greater than the line voltage. Sparking between the



FIGS. 1981 (a) AND (b)

aluminum plates and the surface of the electrolyte can be prevented by covering the surface of the liquid with oil or wrapping the aluminum plate with friction tape to a point about one-half inch below the surface of the liquid. To start a rectifier, it is necessary to place a rheostat or a lamp bank in the alternating-current side to limit the flow of the current until a film of aluminum hydroxide has been formed. To insure good results cleanliness in handling the electrolyte is essential and the salts must not contain too high percentages of sulphates or chlorides. G. C. D. & M. M. B.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

MARCH 1921

Armature Record Tags

Repair shops connected with all the larger street railway systems, as well as some of the smaller ones, have methods of keeping records which, in practically all cases, are different as the system of records used with the various forms have developed along with the growth of the company. In some instances these systems have grown to such an extent as to become expensive to maintain and more or less of a burden, while in others they have been neglected and poorly kept up and in this condition are worthless, for all practical purposes. Like all questions of this nature, there is a wide difference of opinion among master mechanics as to the value and importance of keeping suitable records, which is in part responsible for the wide range of systems of records, reports, forms, etc., found on the various railways properties.

In spite of this condition, all operators seem to agree upon the importance of keeping some specific information as to the condition of their motor armatures, and a great variety of printed forms in the shape of cards and tags are to be found in use. With this in mind, and with the idea of interesting the smaller operators who now largely depend more or less upon the memory of the winder as to the armature troubles and repairs, a sample armature tag will be explained in detail to encourage the keeping of some definite records on this important part of the equipment.

FRONT OF TAG

The general scheme is as follows:—When an armature is taken from its motor frame, the following information should be written, preferably in ink, on the front side of tag by the man in charge of the work.

- Armature Serial Number—Found stamped on the end of the shaft. When shaft renewals are made see that the serial number of the old shaft is stamped on the end of the new one.
- Type of Motor—This is marked on the motor frame or commutator lid.
- Car Number—As painted on the side of the car
- Position of Motor—Location on truck under the car.
- Station—Operating station or motor assembly floor of shop.
- Date—Month, day and year.
- Why Removed—Give briefly reasons for removing the armature.
- Cause of Trouble—What happened to make it necessary to take the armature from the frame.
- Condition of Frame—State condition of field coils, wiring around frame, brushholder, bearings, etc.

The tag, when filled in, is to be signed by the barn foreman and securely tied to the armature shaft.

BACK OF TAG

When an armature reaches the winding room for inspection or repair, the tag should be removed until all work is completed or the armature is ready to be shipped. The tag is then marked with the following information by the winding room foreman:—

- Work Done—All work done on the armature should be checked in the small squares provided in front of the various operations indicated.
- Remarks—In general statements, such as the condition of the insulation on the coils, etc.
- Tested and Approved—Indicate the date work was completed and approved.

This part of the tag should be signed by either the winding room foreman or the shop foreman and the tag tied securely to the shaft before the armature leaves the winding department.

When the armature is received at the car barn or motor assembly floor of the shop, the tag is not disturbed until the armature is put back into service. Before the armature is mounted in a frame, the tag is removed and the following information recorded thereon:—

- Car Number—Number of car on which motor is mounted.
- Motor Number—Location on truck under car.
- Station—Operating station or motor assembly floor.
- Date—Month, day, year.

The card is then signed by the barn foreman and sent to the office of the master mechanic for record and file

ADVANTAGES OF THE PROPOSED TAG

It is suggested that the master mechanic give this tag, modified to meet local requirements, if necessary, a fair trial over a period of from six months to a year, to check the utility of keeping a definite record of armature failures and repairs. The following shows some of the advantages that will result from keeping of such records.

1—It provides an accurate record of armature troubles.

2—It provides an accurate record of armature repairs.

3—It furnishes an accurate record of the location of armatures in the equipment.

4—It provides means of analyzing armature and motor failures. (If the same armature serial is in for repairs, frequently you are in a better position to run down the trouble from the records.)

5—It gives a record of life of motor parts.

6—It helps to weed out defective frames, and troubles due to incorrect winding and motor connections.

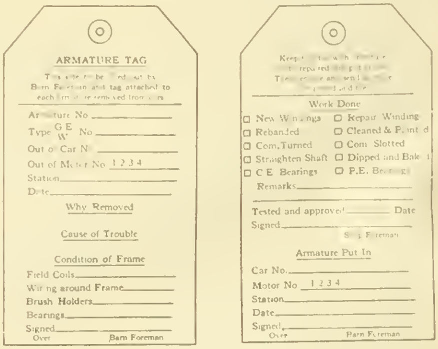


FIG. 1—FRONT AND BACK OF THE PROPOSED ARMATURE TAG

7—It requires little clerical work.

8—It assists in figuring cost of repair parts on armatures.

9—The benefits resulting from the records on these tags will readily be seen and will lead to an extension of this system of records.

SUGGESTIONS FOR TAGS

The following points are suggested as worth considering in connection with the adoption of armature tags for use in railway shops.

1—Adopt a standard size which can be secured from stock, such as 5-3/8 by 2-5/8 inches.

2—A cloth tag is more durable.

3—On some properties the tags are provided with envelopes which can be tied shut, thus keeping the tags clean and making the records more legible.

4—The suggested records should be modified whenever necessary to meet the local requirements more fully.

5—Either file the tags for future record, or record the same information on suitable cards kept in the master mechanic's office.

John S. Dean

THE ELECTRIC JOURNAL

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Radio— Its Future

Looking into the future of radio development one sees possibilities of great expansion in an almost limitless field. The uses to which radio can be put are greatly diversified, and it is certain to create as epochal changes in our accepted everyday affairs as did the introduction of the telegraph and telephone, and the application of electricity to the street railway and to lighting.

Already the commercial transmission of messages by radio telegraphy is well-established. The speed of this transmission and the reliability of the radio systems as compared with wire and cable systems are favorable to the former. For long distance work the radio systems have greater capacity, can handle more traffic and the operation is performed at lesser tolls.

Following the developments of radio telegraphy, great advances are now being made in radiophone development. It is not to be assumed that the radiophone will displace the present wire telephone; rather that it will broaden the field of communication by the development of its own special advantages, which are more or less distinct from those of the wire telephone, as it possesses the feature of widest publicity, as compared with the secret or practically private character of the wire telephone. The two together will make many new applications possible, and it has now become practicable to converse on the sea, in the air or on moving trains, to one's own office or home, exactly as with land telephonic communication.

There is no doubt that in the very near future the radiophone will be largely employed over long distances in sparsely settled districts where other communication facilities are not now available. When it is considered that wherever wire systems reach there must be pole lines which are subject to damage by storms and other agencies, it can be seen how tremendously radio overcomes conditions of cost of installation, maintenance and reliability of service, which cannot be met advantageously by the wire systems.

The adaptability of the radiophone to broadcasting reports, news, entertainments, concerts, lectures, etc., creates a field particularly its own, and it is reasonably certain that the future will see many changes in the present accepted methods of conducting such functions and entertainments. It is quite possible that especially constructed transmitting rooms will be provided for such purposes, so that voices and music will be broadcasted through unbounded areas and listened to by invisible and widely-distributed audiences of vast numbers. The same opportunities would thus exist for the country dweller as for the city resident, and inmates of hospitals and sanitariums, and sick people and invalids in the home would have opportunities for pleasures and diversions [illegible] them. A transmitting system of this character would have the further great advantage of doing away with the necessity of appearing in person in public halls and auditoriums, the capacities of which at best are quite limited.

The importance of reaching such tremendous numbers of people, with practically no effort, offers great possibilities for advertising and the distribution of news and important facts, and in reality introduces a "universal speaking service." It is not unreasonable to predict that the time will come when almost every home will include in its furnishing some sort of loud speaking radio receiving instrument, which can be put into operation at will, permitting the householder to be in more or less constant touch with the outside world through these broadcasting agencies.

The application of radio to industry presents a vast undeveloped field of enormous possibilities. There are great possibilities in all methods of signaling, particularly in railroad operation for the dispatching of trains and for use as a means of communication over areas served by power transmission companies. During the World War it was conclusively demonstrated that radio is an indispensable agency in the directing of air planes and vessels, and in directing and controlling the movement of armies on the battlefields.

To what extent power can be transmitted by radio is as yet problematical, but it is possible even now to perform this important function in a minor way, so that electric relays can be operated at a distance, thus permitting the putting into operation of independent sources of power to direct and control various mechanical devices. As time progresses and knowledge increases, this field will undoubtedly be greatly advanced and developed.

The field of radio application is practically unlimited in the important affairs of the world, and its development will mark one of the great steps in the progress and evolution of mankind. H. P. DAVIS

Radio— Its Relation to the Electrical Industry

The development of the radio art has opened avenues of communication where the rapid transmission of messages was previously impossible and is still impracticable by any other means. For communication from ship to ship or from ship to shore; for communication between airplanes or between airplanes and land stations; for accurately locating directions at long distances for ships and airplanes; for communication between rapidly moving trains and the dispatchers office; for communication to and from regions isolated by deserts, forests or mountains; in

short for quick communication wherever the installation of wires is impossible or prohibitively expensive, radio reigns supreme.

Radio must not, however, be considered entirely from the standpoint of communication. The electrical industry as a whole is closely allied with the radio developments. Some of the greatest advances that have been made in the electrical art in the last decade have been interconnected with devices and circuits of the kind that are used in the radio system. Devices which were no more than experimental laboratory equipment a few years ago, or have developed from laboratory experiments, now are of great commercial importance. As typical examples may be cited the use of tuned circuits at commercial frequencies, such as the impedance bonds, or resonant shunts which form an essential part of 60 cycle signal circuits on 25 cycle electrified railways; the impulse gap lightning arrester; the rectigon or hot cathode rectifier for charging small batteries; the high frequency induction furnace; the telephone relays, which have made transcontinental telephony a commercial possibility; the "wired wireless" system of multiple telephony whereby several telephone conversations as well as a number of telegraph messages are transmitted simultaneously over a single pair of wires—to mention only a few of the more spectacular of such developments.

The electrical engineer had made no application of the electron theory until the laboratory developments of the last decade were transformed into commercial products. More has been learned about the fundamental principles of electricity and the nature of electrical phenomena by the recent researches and developments in this field than in any other. It is reasonable to assume that the deeper insight which is thus being gained into the principles of electro-physics will have a far reaching effect along widely divergent lines of electrical activity. W. S. Rugg

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An Early High Frequency Alternator

Some nineteen years ago, when M. Leblanc, the noted French engineer, was in this country, he asked Mr. Westinghouse for a 10 000 cycle alternator for certain experimental work. Shortly afterwards the machine was designed and built. The results obtained from the completed machine were considered of sufficient interest to present before the American Institute of Electrical Engineers in 1904, and the original publication of seventeen years ago is reproduced in this number of the Journal. As far as the writer remembers, machines of 10 000 cycles per second had been attempted previously, but not in what would now be considered as satisfactory constructions. He undertook to design this machine along thoroughly practical lines. In fact, the general tendency in very recent high frequency alternators for radio work on the continent, in Japan and now in this country, is so nearly along the lines of this early machine that M. Latour, the well known French engineer, has designated this early machine as the "normal type".

Previous to this early machine, apparently all attempts were along constructions without iron in the armature. Such machines, in general, have been tried repeatedly, for ordinary frequencies, and all have been abandoned. In other words, the iron-cored type of alternator has been the only survival for any kind of service. This early machine, built by the Westinghouse Company, may, therefore, be said to have anticipated modern high frequency construction in general, and even in detail for certain designs. In working out the designs for some high frequency radio machines of large capacity, quite recently, and considering all the possible types and constructions, the whole matter narrowed down finally to a construction which is almost identical with this machine of nearly nineteen years ago.

In the design of this machine, nineteen years ago, the writer recognized that, from the mechanical standpoint, an iron-cored construction for the armature was a practical necessity, if a reliable and durable machine were to be obtained. An iron core, at this high frequency, was considered by many to be impracticable, due to the probability of excessive iron losses. Recognizing this probable limitation, the writer undertook to make the design practicable by so finely laminating the armature core that the losses would be brought within operative limits. Apparently this was the first very high frequency alternator with very thin laminations.

This early machine was of the inductor type, not because the inductor type in itself is superior magnetically or electrically over other types, but simply because it lent itself mechanically to high frequency constructions. This was fundamental, as evidenced by the general adoption of the inductor type for modern very high frequency alternators.

This little machine of nineteen years ago was of relatively small capacity, based upon the methods of rating of those days. As the published results show, the machine carried a load of two kilowatts with an armature iron temperature rise of 16 degrees C. and a copper rise of 21 degrees C. by resistance. With modern means of cooling and methods of rating, this machine probably could be made to carry something like five times this load, under which conditions it would show a quite respectable efficiency for a small high frequency machine.

This was a prideworthy little alternator, in view of the fact that it was a first adventure into a practically unknown field; and also because high frequency machines of fifteen to twenty years later are so nearly along the same lines that it may be assumed that most of the advances in the construction of such apparatus have been in improvements in materials and in means for dissipating heat. This first machine was sent to M. Leblanc, in France, many years ago, and the writer has heard nothing about it since. It is quite possible that it is still in existence. B. G. Lamme

Epoch Making Radio Inventions of Fessenden

S. M. KINTNER
Vice-president,
The International Radio Telegraph Co.

EVERY art has its outstanding leader,—some genius that is gifted with a foresight almost akin to prophesy. So remarkable are many of their inventions, so far ahead of their time and the practice of the art, that they are not appreciated until years elapse and the art grows abreast of their teachings and learns their value.

Fessenden is such a genius in the radio art. To anyone who learns of his accomplishments, by comparing his teachings, as recorded in the files of the United States Patent Office, with the almost universal practice of the radio art of today, the truth of the foregoing will be apparent.

Fessenden is never satisfied to follow the "beaten" path. He is always looking for other ways of doing things. At times he chooses the wrong lead, but he is quick to realize his mistake and to go back and try some other.

It is this inborn characteristic of his, of being dissatisfied with things as they are and of always trying to improve them, that compels him to invent. It is a keen realization of how things work, and an almost superhuman analysis of the relative importance of the many factors that influence the result, that makes his inventions so pioneer in character.

In 1899, when the radio art, then called "wireless", was in the beginning and the scientific world was singing the praises of the "coherer", a detecting device that was then said to be the most sensitive electrical instrument ever invented and so was the one thing that made "wireless" possible, Fessenden said: "No, that is all wrong. The coherer will not be used at all in a short time."

The coherer was a trigger device which was tripped when the incoming signals were of sufficient strength, and so released energy from a local source, which actuated the indicating means. The signals had no character. One station could not be distinguished from another by the sound of its signal spark. Fessenden said: "No detector will survive that has such characteristics."

He started to work at once to discover a detector that would give a response proportional to the received energy,—one that utilized all of the received energy and was constantly in a receptive condition. He found not only one such detector, but several. Of these, the liquid barreter is the best known and was most widely used. The liquid barreter held first place among detectors from 1903 until about 1909.

Fessenden's early discovery of this type of detector, which enabled him to get quantitative results, gave him a big advantage over the other early workers in the art who continued to cling to the coherer. With this form of detector, he was early brought to a realization of possibilities of radio that were unthinkable with a coherer.

The invention, then, of this type of detector, marks the first epoch in Fessenden's inventions. Also it marks the beginning of a new form of radio transmission. The coherer worked best when the radiated energy was like a "whip crack", an explosion like the exhaust of an automobile engine with the muffler open. It required a big shock to trip it; and all that followed, until it was reset, was wasted. Fessenden's device, on the contrary, used all the received energy, and so could have it fed out from the transmitter more gradually. It was by anology, like exhaust from the automobile engine with the muffler in use.

The advantage of the Fessenden method over that preceding was in the tuning of the receivers. This tuning made it possible to select one from several simultaneously operating transmitting stations, each sending on a different wave length, and to exclude the others.

The results secured were so good that Fessenden sought to improve them still further; and he had the marvelous conception of producing continuous radiation by directly connecting a source of alternating current, such as a high-frequency alternator, to the antenna, with no spark gap employed in any part of his system.

It is no doubt difficult for newcomers in the art, now that all of the successful trans-atlantic radio transmitting stations employ that method, to realize how radical a departure he made from the practice of the day. It may, however, serve a useful purpose to throw a side light on this invention by quoting from no less an authority than Dr. J. A. Fleming, who says*:—

> The patentee (Fessenden) considers that if such an aerial, (one described as having large capacity) were associated with an inductance and an alternator directly, no spark gap being used, it would radiate very long electric waves. It is doubtful, however, whether it would do so. The creation of an electric wave seems to involve a certain suddenness in the beginning of the oscillations, and an alternator giving a simple sine curve electro-motive force would not be likely to produce the required effect unless the frequency of the alternator was extremely high."

Fessenden had no dynamo of the kind he required, but he knew what characteristics such a machine should have, and plainly stated them in his patent which was issued in 1902. Furthermore, he set about getting such a machine; and, after untiring efforts on his part, and a great development expense borne by his financial

*In the 1906 edition of his book entitled "The Principles of Electric Wave Telegraphy"—p. 511.

backers, he succeeded in securing one from the General Electric Company in Sept. 1906.

Another radical departure was made in addition to the proposal to use a dynamo,—that was the recommendation to use a frequency of 100 000 cycles per second instead of 1 000 000, or more cycles, as was then thought necessary. How much of a departure that was, will be appreciated when it is realized that the radiation varies as the square of the frequency, hence with one-tenth the frequency, but one-hundredth of the energy will be radiated for the same antenna current in the same aerial. There are, however, other factors that enter, particularly in the long distance transmission, that more than overbalance the apparent loss, and today the world's most powerful station has a frequency of only 12 500 cycles,—a wave length of 24 000 meters.

The invention of the method of continuous generation is Fessenden's second epoch making contribution to the radio art.

With a detector and receiver that gave quantitative indications and with the idea of continuous radiation, Fessenden conceived the plan of controlling the radiation in accordance with sound waves and thus having a radio telephone. He proceeded to test out his idea, and was successful in proving it, several years before he secured his dynamo to produce continuous radiation, by the use of modulated waves from spark discharges at the rate of several thousands per second. However, very shortly after receipt of his first high frequency alternator, he was able to transmit radio phone messages over distances of several miles. In some of these early demonstrations, he perfected methods of control of the radio phone which enabled him to talk from a wire line phone to the radio station, where the received message was automatically and accurately relayed over a number of miles by radio telephone, and at the radio receiving station was again automatically put back on the wire line for delivery to the distant person listening.

The radio phone is the third epoch making invention of Fessenden.

There are a number of other Fessenden radio inventions that merit some mention, but space limitations make it necessary to omit all but one more, the heterodyne*. The heterodyne method is the best yet devised for the reception of continuous, or undamped waves. It, with continuous wave generation, has made trans-atlantic radio operations practicable.

The heterodyne then is the *fourth* epoch making radio invention of Fessenden.

What other radio inventor, American or Foreign, can point to as many inventions of equal importance?

*See article on this subject by Mr. J. V. L. Hogan, in this issue, p. 116.

The Lafayette Radio Station

COMMANDER S. C. HOOPER, U. S. N.

THE Lafayette high-power radio station at the village of Croix d' Hins, France, about fifteen miles from Bordeaux, the construction of which was undertaken during the war by the United States Navy in conjunction with the French authorities for the purpose of insuring adequate and reliable communication facilities between the United States Government and the American Expeditionary Forces in France, was formally turned over by representatives of the Navy to the French Government on December 18, 1920, and the station was then formally inaugurated in the international wireless service of the world.

The construction of a super high-power radio station in France was deemed necessary after the entrance of the United States into the World War, in view of the extremely heavy and constantly increasing volume of trans-Atlantic traffic being handled by the ocean cables, and the not remote possibility that this means of communicating with our forces abroad might be interrupted.

It was decided, therefore, to establish a super high-power radio station in France which would be capable of communicating with the American stations during all periods of the day and night and all seasons of the year regardless of possible interference from the powerful station at Nauen, or from atmospheric disturbances prevailing during the summer months. Accordingly the Navy Department was entrusted with the task of establishing a station in France which would be not less than twice as powerful as any radio station then in existence.

The construction of the station was far advanced when the armistice was signed, at which time, however, all work was stopped, as the very urgent need of the station was no longer apparent. Later, however, the French Government requested that the station be completed as an after war measure, and work was again resumed and carried to completion.

The principal engineering features of the Lafayette radio station are eight self-supporting steel towers each 820 feet in height, resting on immense concrete foundations which rise 12 feet above the ground level; the antenna system, and the transmitting equipment consisting of 1000-kw arcs complete in duplicate.

The eight towers, resting on their foundations, thus providing a height of 832 feet from the ground level to the tops of the towers, are arranged in two rows of four each, the rows being spaced 1320 feet, and the towers in each row likewise being spaced 1320 feet apart; giving a total antenna area of 5 227 200 square feet, this

antenna area far exceeding that of any other existing radio station.

The antenna is of the inverted "L" type, the longitudinal antenna wires, consisting of number three silicon-bronze cable, being supported by triatics stretching across the aisle formed by the two rows of towers.

The arc equipment is of the Federal Poulsen type and is capable of withstanding a 25 percent overload, thereby making 1250 kw available intermittently for short periods of time. The contract for the arc transmitting equipment called for the delivery of a high frequency current of 500 amperes continuously on a wave length approximately three times the natural period of an antenna having a true capacity of 0.047 microfarad

FIG. 1—MAIN BUILDING AND 820 FOOT SELF-SUPPORTING STEEL TOWERS OF THE LAFAYETTE RADIO STATION

and a total continuous undamped wave radio frequency resistance, exclusive of radio apparatus and connections, not to exceed 1.3 ohms under operating conditions.

The characteristics of the antenna system and oscillatory circuit, as permanently installed, are outlined below:—

Capacity	0.05 microfarad
Antenna resistance	0.45 ohm
Ground resistance	0.90 ohm
Loading inductor and connections	0.30 ohm
Total oscillatory circuit resistor	1.65 ohms
Antenna natural period	8130 meters
Effective antenna height	172 meters

The average height of the antenna horizontal wires is 650 feet, which shows the average sag of the wires to be 182 feet, since the tops of the towers are 832 feet above ground level. The equipment was adjusted to five wave lengths, namely, 13 900, 16 300, 18 700, 21 200 and 23 500 meters, the latter being considered as the contract wave length for the purpose of acceptance tests. A maximum antenna current of 610 amperes was obtained without damage to the installation. The antenna current used during the 30 day tests, which were conducted from August 21st to September 19th, 1920, averaged about 450 amperes on the various wave lengths.

The signals from the Lafayette station as received at Cavite, Philippine Islands; San Francisco, California; Balboa, Canal Zone; Bar Harbor, Maine, and Washington, D. C., during the 30 day tests, were of from three to eight times greater intensity than those of other high-power radio stations of the world of approximately equal distances.

Work on the station began on May 28, 1918 and was completed on August 21, 1920. The total cost of

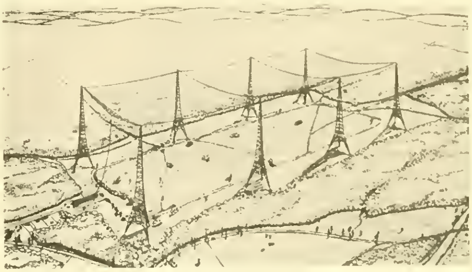

FIG. 2—LAFAYETTE RADIO STATION

The largest radio station in the world. Height of tower, 820 ft; height to top of portal, 215 ft; distance between legs at bottom 220 ft; distance between legs at portal, 105 ft; distance between legs at top, 9 ft. 8.5 in.; weight of tower, 550 tons; distance between towers, 1312 ft. 4 in.; range of operation, 12 000 miles.

the station, which the French Government has agreed to assume, was approximately $4 000 000.

A commemorative tablet has been placed on the radio power building near the main entrance, bearing the following inscription in both English and French:

LAFAYETTE RADIO STATION

Croix d'Hins, Gironde, France

In Honor of General Lafayette

Conceived for the purpose of insuring adequate and uninterrupted trans-Atlantic communication facilities between the American Expeditionary Forces engaged in the World War and the Government of the United States of America.

Erected by the United States Navy in conjunction with and for the Government of France.

It is understood the Lafayette station will exchange trans-Atlantic radio traffic with stations in the United States and across the continent of Europe and Asia with the French station at Saigon, Indo-China, and also with other high power radio stations in various parts of the world.

Description of a Uni-Wave Signaling System for Arc Transmitters

LIEUT. W. A. EATON. U. S. N.

UNTIL a comparatively recent date, most arc radio transmitting stations, both on shipboard and on shore, used various modifications of the so-called "Compensation" or "Spacing" wave signaling system, that is, a system whereby the transmitting or "Marking" wave of a definite frequency is propagated when the sending key is depressed, and a compensating or spacing wave of a different frequency is propagated when the key is open. The only exceptions to this system in use to any extent were arc transmitters of low power, of the order of two and five kilowatts, in which the power handled and the characteristics of the arc were such that the elimination of the compensating wave was somewhat easily accomplished.

The compensation wave method of signaling limits the number of arc stations which can be simultaneously operated, for the reason that each station requires the exclusive use of a definite wave band, the width of which is determined by the fact that there must be from one to three percent separation between the signaling and compensating waves. Also, as is well known, the arc is rather prolific as regards harmonics and "mush", which annoying source of interference is doubled when the compensation method of signaling is used.

The chief advantage of the compensation method of signaling was its simplicity. In the early days, with comparatively few sustained wave stations in operation, its use offered no great disadvantages. As the number of sustained wave stations increased, however, objections to the method became so pronounced that indications are that the coming International Radio Convention will decide against the continued use of the compensation method of arc signaling.

The necessity of developing a suitable "uni-wave" or single wave signaling system, therefore, was evident. A great deal of experimenting and research work along this line has been in progress during the past two or three years, both in Government and commercial establishments, with the result that today it is safe to state that, as regards this country, the problem has been solved for arcs of all powers now in use.

The problem that confronted the Navy was the development of a uni-wave system which would not be too critical in adjustment and would give positive and consistent operation. The consideration of various schemes and circuits indicated that the most positive uni-wave signaling would be accomplished by a circuit in which the arc was connected to the antenna when the transmitting key was depressed and to a dummy antenna or so-called "back shunt" circuit when the key was opened. And this is the scheme which is today in successful operation in a few semi-high powered stations and is gradually being expanded into more.

A simple circuit accomplishing the above results has been in successful use with two kilowatt arcs, and is shown schematically in Fig. 1. Position I shows the arc connected to the antenna with the transmitting key depressed; position II shows the arc momentarily connected to both the antenna and back shunt circuit upon the opening of the transmitting key, and position III shows complete separation from the antenna and positive connection to the back shunt circuit. Upon again pressing the key, the operation is reversed.

While the above scheme was applicable to the two kilowatt arc, it was not applicable to high powered arcs, due to the violent flashing experienced at the contacts when the energy was transferred from the antenna to the back shunt circuit or vice versa. A circuit was therefore devised which, retaining as far as possible the initial intent of completely disconnecting the antenna and back shunt circuit, makes use of a bank of non-inductive resistance units between the arc antenna and back shunt circuits as indicated in Fig. 2. It will be noted that the key in this circuit introduces a comparatively high resistance, alternately into the antenna and absorbing circuits, thus rendering the circuit in which the resistance is introduced aperiodic for all practical purposes. Tests of this circuit gave early indication of a satisfactory uni-wave system. Not only is the sparking at the key contacts reduced to an absolute minimum, due to the fact that the antenna and absorbing circuits are not entirely broken, but it was found that the adjustments of the constants of the back shunt circuit are not at all critical, either in wave length or current balance.

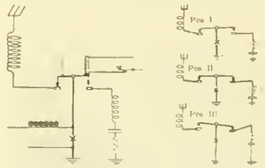

FIG. 1—UNI-WAVE OR SINGLEWAVE SIGNALING SYSTEM

Disconnecting antenna and back shunt circuit for arc radio transmission.

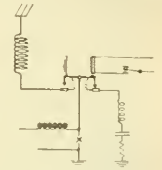

FIG. 2—USING RESISTANCE BETWEEN ANTENNA AND BACK SHUNT CIRCUIT

Thorough tests were made on this circuit to determine the most suitable form of key and the best constants for the back shunt circuit. Little difference was noticeable in the action of the different keys tested, however, and the transfer of energy from the antenna

circuit to the back shunt circuit took place efficiently when the constants of the back shunt circuit were varied through wide limits. The adjustments are thus not critical and all tests made, indicated that the two circuits operated entirely independently; the key serving primarily to transfer the arc from the antenna circuit to the independent or back shunt circuit.

The final circuit, which was found to work most satisfactorily, is shown in Fig. 3, and consists of the following component parts:—

a—A transmitting key, including non-inductive resistance units.
b—A back shunt circuit resistance.
c—A back shunt circuit inductance.
d—A back shunt circuit capacity.
e—A double contact relay.
f—A Morse key.

The Transmitting Key:—The relay key consists of eight pairs of contacts, one contact of each pair being stationary. Four pairs, connected in series, are used for making and breaking the back shunt circuit and the other four, also connected in series, are used for the antenna circuit. Each pair of contacts is bridged by a non-inductive resistance. Thus, when either the antenna or back shunt circuit group of contacts is open, four of the resistance units are in series with that circuit increasing its resistance by a like amount. The relay key is actuated by two solenoids, the energizing of which is controlled by a separate double contact relay.

The adjustments of the transmitting key must be maintained at all times, so that all contacts of each group make and break simultaneously. While this requirement is imperative, its fulfilling is comparatively simple, since the design of the key has been made to facilitate this adjustment. If this adjustment is not properly made, it will evidence itself by heavier sparking at the contact which is not in alignment. When properly working, the sparking at the contacts should be extremely minute. It has been found that the antenna contacts spark even less than those of the back shunt circuit, no sparking at all being visible the greater part of the time.

The radiation ammeter is connected in the common lead from the arc to the antenna and back shunt circuits, so that the meter indicates the current in either circuit.

The Back Shunt Circuit Inductance is of about 150 microhenries for an arc in the order of 30 to 60 kw, and is made adjustable, so as to facilitate balancing between the two circuits.

The Back Shunt Circuit Capacity consists of a bank of standard 0.004 mf. mica condensers connected in parallel. For an arc on a wave length of about 5000 meters, and an antenna radiation of about 45 amperes, five condensers are used.

The Double Contact Relay, which may be of a common commercial type, is actuated from the contacts of a Morse key and is provided with a double contact armature; each contact controlling one electric magnet of the transmitting key.

The fact that the constants of the back shunt circuit are not critical as regards current balance or wave length, makes it possible to adjust this circuit initially so that no re-adjustment is required when the transmitted wave length is changed through wide limits.

The current in the back shunt circuit should be adjusted so as to be approximately equal to the antenna current. This may be readily accomplished by an adjustment of the back shunt circuit resistance and inductance. While a balance between the two circuits is

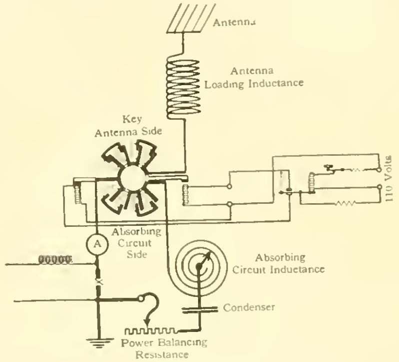

FIG. 3—SCHEMATIC DIAGRAM OF UNI-WAVE ARC RADIO TRANSMITTER

Final circuit which was found to work most satisfactorily.

not essential for satisfactory operation, the balance, nevertheless, should be made so that the load on the power equipment will be held practically constant.

The use of the above key in practical operation has shown that the emitted wave from the arc is greatly improved in tone and as a rule resembles that of an alternator or valve set. Also the radiation will be found to have increased as a rule by as much as 12 percent with a very noticeable reduction in arc harmonics and mush. The current remaining in the antenna when the Morse key is raised is negligible, being in the order of 1/4 to 1/2 ampere out of 40 amperes normal radiation.

One of the above signaling systems has daily been in successful and consistent operation at a station where the average antenna current is in the order of 75 amperes. This current is handled by the key with perfect ease and freedom from sparking at the contacts.

The Heterodyne Receiver

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Manager,
The International Radio Telegraph Co.
Past President,
Institute of Radio Engineers

OF THE many inventions in the applied science of radio signaling, a few stand far above all the others. The heterodyne receiver marks one of the highest peaks of achievement in wireless communication, and probably has done as much to advance the art as any single invention. When Fessenden devised this ingenious and eminently practical way of selecting and amplifying received radio signals, he established a system which, in conjunction with his continuous-wave transmitters, now bids fair to grow into substantially universal use.

The coined name "heterodyne" is derived from the Greek *heteros* (other) and *dyne* (force), the new word implying that the receiver, which it designates, makes use of an "other force", i.e., a force other than that of the received signals. The heterodyne does truly utilize such a second source of energy, for it combines with the signal-producing effects of the received electromagnetic waves, the effects of another series of radio frequency oscillations which are locally generated at the receiving station. The invention is notable not so much for the fact that a local source of energy is used, as for the highly novel and effective ways in which the effects of the local source are combined with those of the incoming signals.

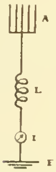

FIG. 1 SIMPLE RECEIVING SYSTEM

In order to demonstrate the action of the heterodyne receiver, let us first look into the basic problem of receiving sustained-wave radio signals. The sustained or undamped wave is a progressive electromagnetic vibration of ultra-audible but infra-visible frequency. This wave is created by the surging of powerful alternating-currents, of similar radio frequency, in an elevated aerial wire system at the transmitting radio station. The sustained wave passes out radially over the earth's surface in all directions from the transmitter; as its energy is distributed over a larger and larger area the wave amplitude decays, and at any receiving point it is obviously very feeble as compared to its initial value. Nevertheless, such an electromagnetic wave, in passing a receiving aerial-wire system, is capable of setting up in the elevated conductors a small radio frequency alternating potential with respect to earth. If a circuit from aerial wire to earth is provided, a feeble radio frequency current will flow; if the capacity reactance of the aerial wires with respect to earth is balanced-out (for the frequency of the arriving waves) by the inductive reactance of a tuning coil in the circuit, the current will build up by resonance to a maximum value.

Fig. 1 shows an aerial wire system A connected to earth E through such a tuning coil L and a very sensitive current-indicator I. If we assume that radio waves of a frequency of 100 000 per second (which is equivalent to a wave-length of 3000 meters, the wave velocity being 3×10^8 meters per second) strike the antenna A, it will necessarily follow that a small alternating voltage of this same frequency will be induced in the system. Since the circuit is in effect closed for currents of this frequency (because the capitance of the aerial wires with respect to earth may be of the order of 0.001 microfarad), the voltage will result in a small 100 000 cycle alternating current in the system. If the antenna capacitance of 0.001 microfarad is offset by making the inductance of the coil L approximately

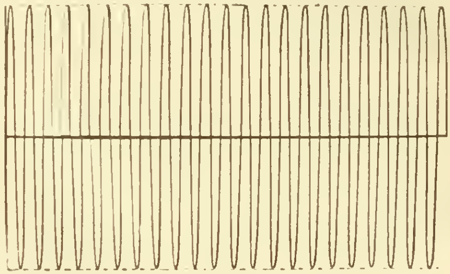

FIG. 2 SUSTAINED WAVE

2.5 millihenrys, the circuit will have minimum reactance for 100 000 cycles and consequently a maximum current will be developed. Under these conditions a powerful disturbance might produce as much as one milliampere of current through the indicator I, but the usual quantity would be measured in tens of microamperes.

An oscillogram of the antenna-to-ground current is shown in Fig. 2; a complete cycle occupies one one-hundred-thousandth of a second, so that the twenty-two cycles represented in this figure consume only a little over one five-thousandth of one second. The amplitude is constant; hence the name "sustained" or "continuous" or "undamped" wave. Telegraph signaling with such waves is usually carried on by interrupting their continuity: a stream of waves is emitted (and hence received) for about one-twentieth of a second to represent a dot and for about three-twentieths second to indicate a dash. These signal trains of constant amplitude waves produce, in the receiver, groups of

constant amplitude radio frequency current of similar duration. The problem of receiving radio telegraph messages thus resolves itself into that of observing the duration of these feeble alternating currents of exceedingly high frequency.

If the indicator of Fig. 1 were of the thermal type and capable of showing a substantial scale reading for a few millionths of an ampere, it might be used as a rather crude telegraph receiver. Could such an apparatus be secured, a short deflection would indicate a dot and a long deflection or pause a dash; telegrams in the Morse code could thus be spelled out slowly. In wire telegraphy aural reception was found to be far more satisfactory than visual operation; the same is true of radio telegraphy, and therefore we must find a way of generating sounds to indicate the radio frequency currents in the receiving circuits.

The telephone receiver is the most sensitive and most satisfactory device for producing sounds from electricity. However, a current of 100 000 cycles per second frequency is many times too high to give a direct indication from a telephone receiver; even if it were possible to make the diaphragm vibrate at this rate, no sound would be heard because the upper limit of audibility is exceeded by some five times. Consequently some type of frequency transformation or lowering must be used.

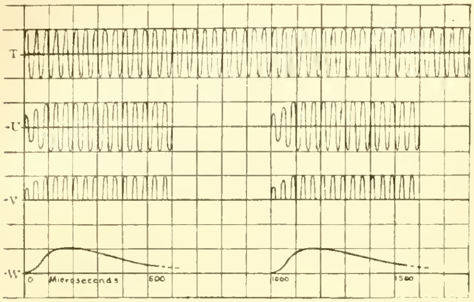

FIG. 3—OPERATION OF CHOPPER RECEIVER

Fig. 3 indicates oscillographically one of the most successful methods in use prior to general adoption of the heterodyne. On the uppermost axis T is shown the train of oscillations in the receiving antenna during part of a dot-signal. By inserting an interrupter or "chopper" somewhere in the circuit the oscillation-train is broken up into shorter groups about 0.001 second apart, as indicated on axis U. These shorter trains are rectified or biased by passage through a distorting conductor (e.g. a crystal detector) as represented on axis V, and the rectified half waves are collected in a condenser and discharged as direct current pulses, axis W, through the windings of a telephone. Thus there will be current in pulses at 1000-per-second frequency in the telephone so long as waves are arriving. These will produce a musical vibration of the diaphragm; short and long tones of a pitch about two octaves above middle C will indicate dots and dashes. The pitch of the signal tone may be changed, by altering the interrupter speed, to a value most pleasing to the operator.

The "chopper" exists in a number of modifications, but all are handicapped in much the same way. Interrupter troubles are common, usually much of the arriving energy is wasted and there is little or no selective power inherent to the system. The prime defect is that all current impulses in the antenna circuit, practically regardless of their character or frequency, are "chopped-up" into the same musical tone as the signal. Thus the telephone receiver gives the same type of response to interfering signals as to that which it is desired to receive, and it becomes exceedingly difficult to interpret arriving messages under any but the best conditions.

The heterodyne receiver offers a violent and favorable contrast. Abandoning all devices of the interrupter class, Fessenden* devised a frequency reducing scheme based upon the principle of beats. It was well known that if two musical tones of slightly different frequency were simultaneously sounded, an auditor would hear not only the two notes, but also a flutter or

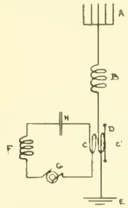

FIG. 4 DYNAMIC HETERODYNE

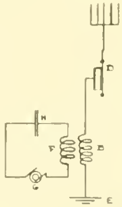

FIG. 5 ELECTROSTATIC HETERODYNE

amplitude variation whose rate would be equal to the difference in the tone frequencies. By the exercise of a great scientific imagination, Fessenden extended this concept to the range of radio frequencies, far above the limit of sound audition. His suggestion was not merely that, if a radio frequency effect of say 100 000 cycles per second were caused to interact with another of say 101 000 per second, a beat variation of 1000 per second (an audible frequency) would be produced; Fessenden went farther, and proposed the use of a generator located at the receiving station for the production of one of the two radio frequencies. By placing the second generator under the control of the receiving operator Fessenden made it a "frequency determining element" by means of which the operator at the receiving station could control the pitch of tone of the arriving signals and also that of interfering signals of different but adjacent radio frequencies. Further, by utilizing a radio frequency generator at the receiving station, Fessenden's heterodyne permitted a great economy in power. None of these features would have been possible had he not recognized that the generator of one of the two radio frequencies whose effects are

*U. S. Patents 1050441 and 1050728, R. A. Fessenden

combined could be allowed to run continuously,—i.e., that, since beat signals would be produced only when both frequencies affected the receiver, it was necessary to cut up only one of them into dots and dashes at the transmitting station.

Fig. 4 shows one of the earliest forms of heterodyne receiver. The aerial to ground oscillations flow from the antenna *A* through coil *B* and *C'* to earth *E*. Coil *C'* is of small dimensions and is carried on a mica diaphragm *D*. Near it (the assembly constituting a dynamometer heterodyne telephone) is mounted a fixed coil *C*, through which flows the local oscillatory current generated by the radio frequency alternator *G* in the circuit *F H C G*. By making the local frequency slightly different from the arriving frequency, the resultant force produced upon the diaphragm *D* by the interaction of the alternating-current fields of coils *C* and *C'* will produce a to-and-fro motion of a frequency equal to the difference between the two oscillation frequencies. Thus, if the received waves have a frequency of 100 000 cycles per second and the local generator runs at 101 000 cycles, the diaphragm will vibrate at 1000 cycles per second and give off an audible signal beat note so long as waves arrive from the transmitter.

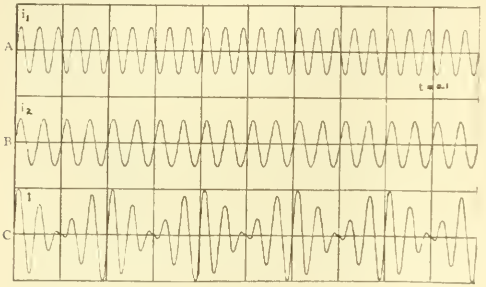

FIG. 6—FORMATION OF BEATS

A study of the dynamometer heterodyne will bring out the fact that the intensity of signal response is dependent not merely upon the strength of the received waves, but also on the strength of the local current. Thus the receiver gives strongly amplified tones from the desired signals; undesired signals of even slightly different frequencies will produce beat tones of a radically different pitch, and these are usually of proportionally smaller amplitude. Furthermore, the heterodyne receiver will give maximum amplification only when the received waves are purely sustained, for such sinusoidal oscillations are essential to maximum beat formation. This means that impulsive or irregular interfering disturbances, such as are produced by spark transmitters or by atmospheric (static) strays, will not be amplified nearly so much as the desired signals. All this is due to the unusual type of selective polarization utilized in these heterodyne receivers. By this function an exceedingly valuable means of discriminating between desired and interfering signals has been provided.

Fessenden pointed out that interaction between electrostatic fields might also be used for heterodyne reception. This arrangement, which utilizes voltage instead of current effects, is shown in Fig. 5. Here the antenna circuit passes from *A* through the electrostatic telephone *D* and inductance *B* to earth *E*. The electrostatic telephone consists of a conducting diaphragm supported close to a fixed plate, the two forming a condenser. When a voltage is impressed upon the two plates an attractive force is set up between them and the diaphragm moves toward the fixed conductor. By varying the charging potential at audible frequency a tone may be produced.

In using the electrostatic telephone for heterodyne reception, it is necessary to apply to the telephone not only the signal voltage but also the locally generated potential. This may conveniently be done by the inductive coupling between coils *F* and *B* of Fig. 5, coil *F* being in circuit with the local generator *G* and the tuning condenser *H*. Under these conditions the operation may be graphically represented as shown in Figs. 6 and 7 although, for convenience of drawing, the frequency ratio is greater than in radio practice. Referring to Fig. 6, the curve of axis *A* may be taken to represent the voltage impressed upon the condenser telephone by the arriving signal. The curve of axis *B* will then represent the potential due to the local generator. This is evidently of a different frequency, the ratio of *A* (frequency N_1) to *B* (frequency N_2) being 1.25 in these diagrams. The curve along axis *C* shows the algebraic sum of the potentials on *A* and *B*; by reason of the difference in frequencies this resultant potential fluctuates from maximum to minimum at the beat frequency or $N_1 - N_2$ cycles per second, as indicated.

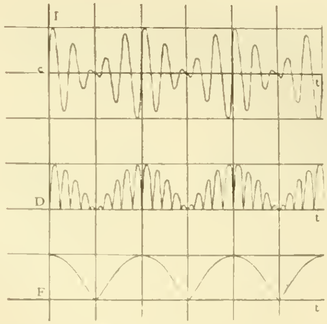

FIG. 7—RECTIFICATION OF BEATS

The curve of axis *C* is repeated at the top of Fig. 7. Axis *D* shows the same pulsating radio frequency voltage in effect completely rectified; this is the process performed by the electrostatic telephone, for, although there is in it no electrical rectification or biasing, the device nevertheless produces a unidirectional mechanical force regardless of the polarity of the applied potential. Thus on axis *D* we have a graph of the mechanical

force applied to the diaphragm of the condenser telephone, as it acts in its capacity of a perfect electromechanical rectifier. The diaphragm itself by reason of its inertia, cannot follow the rapid individual attractions, but will execute an averaged vibration somewhat as shown on axis *E*. This slow vibration is of the beat or audio frequency, and consequently gives rise to an audible signal tone, just as in the case of the dynamometer or electromagnetic heterodyne of Fig. 4.

The electrostatic heterodyne possesses the same amplifying and discriminating characteristics as the other forms, and is somewhat more sensitive than the dynamometer form. With high receiving aerials, and particularly with radio frequency amplifiers, it is not difficult to copy transoceanic signals with the electrostatic heterodyne. Without amplifiers, but using the large antenna of the Navy station at Arlington, Va., (which has a maximum height of 600 feet), and a small Poulsen arc as the local source of oscillations, signals have been received from San Francisco with the electrostatic telephone heterodyne.

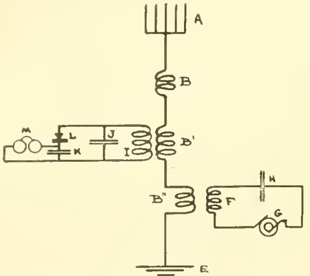

FIG. 8—TYPICAL CIRCUIT OF RECTIFIER HETERODYNE

A great increase in sensitiveness of the heterodyne receiver was secured by combining the local source of oscillations with an electrically rectifying radio receiver*. A typical arrangement of this sort is shown in Fig. 8. Signal currents are impressed upon the rectifying detector *L* from the antenna *A* and across coupling *B' I*. An incoming wave of constant amplitude will produce a constant radio frequency potential across the detector, and this will result in a uniform direct current through the telephones *M*. When radio frequency currents of slightly different frequency, from generator *G*, are also impressed upon the detector by way of the inductive couplings *F B''* and *B' I*, a radically changed condition exists. The local voltages interact to produce potential beats across the detector; the rectifying system is subjected to fluctuating voltages such as appear on axis *C* of Fig. 7 so long as both radio frequencies are applied. These beat-voltages are inevitably rectified into a fluctuating or pulsating direct-current, which passes through the telephone windings and produces a beat-tone signal.

Since the electrical rectifier-telephone combination is of great sensitiveness, its application to heterodyne reception has made it possible to receive selectively over great distances with comparatively small antenna structures. By proper choice of detector characteristics, the high powers of discrimination and amplification are also secured in this form of heterodyne, and, since its output is a varying audio frequency electrical current, it lends itself to combination with amplifiers, electrical tuning systems, etc.

Fig. 9 illustrates the soundproof receiving room of the Arlington Naval station, where some interesting early long distance work with the rectifier-heterodyne was done. On a special series of experiments, messages were copied several times every day from the

FIG. 9—HETERODYNE RECEIVER AT THE ARLINGTON RADIO STATION

U. S. S. Salem as she steamed to Gibraltar. By combining the signals with local oscillations generated from the small arc shown at the right of the photograph, the heterodyne amplification secured made it possible to read messages sent by the ship long after she had gone so far that her signals could not be understood when ordinary receivers were used. Developments of the heterodyne since this work in 1911 have kept it at the head of the list, and by its exceptional sensitiveness and selectivity, it has made possible the long-distance communication records which have been announced in the past few years. Although the type of transmitter used may vary largely, and while various auxiliary devices may be combined with the receiver, every exceptional radio performance of recent years has depended for its success upon the same principle. In every case the receiver has embodied some form of the rectifying heterodyne.

*U. S. Patent 1 141 717, Lee and Hogan.

The Foundations of Modern Radio

L. W. CHUBB and C. T. ALLCUTT

THE year 1900 really marked the beginning of commercial radio telegraphy. Although Marconi's experiments with Hertzian waves began in 1895, it was not until 1899 that he achieved results that indicated unmistakably the commercial utility of radio communication. Public interest in this new form of communication was first aroused by the then spectacular feat of transmitting messages by wireless across the English Channel. When Marconi accomplished this in March 1899 he opened the eyes of the world to the practical significance of his heretofore little known work.

Later in the same year Marconi came to the United States and employed his wireless system between a ship and the shore for reporting the progress of the International yacht races. This feat resulted in still more publicity for radio telegraphy and a more general appreciation of its possibilities for carrying on communication to and from vessels at sea. The maritime possibilities of radio were further emphasized by the use of radio for communication between war vessels during the manoeuvres of the British Navy in July and August, 1899.

These demonstrations of the practicability of radio communication were soon followed by definite steps towards the establishment of regular commercial ship-to-ship and ship-to-shore telegraph service, and by the end of 1900 the position of wireless telegraphy as an indispensable aid to navigation and naval operations was firmly established.

The radio station of 1900, however, was a very different thing from the station of today. A spark coil was used for transmission and a coherer for reception. Continuous wave transmission had never been heard of and the vacuum tube was yet to be invented. The difference in efficiency and reliability that but twenty years of progress has brought about makes radio communication a splendid monument to the ingenuity of the many able investigators who have contributed to the advancement of the art. Indeed there are few modern engineering developments in which so many men of high scientific attainments have taken part.

In spite of the number of men who have aided in the advancement of radio, the notable landmarks in the progress of the art are relatively few in number. In fact, the real epoch-making achievements since 1900 are but four in number. These are—

1—Continuous wave transmission.
2—Heterodyne reception.
3—The vacuum tube.
4—The feed-back circuit.

While many other meritorious contributions have been made toward the progress of the radio art, nevertheless, the four inventions mentioned above represent the four great achievements upon which modern radio is founded and upon which the future of the art depends.

Continuous wave telegraphy was advocated by Prof. R. A. Fessenden as early as 1900, although it was not until some years later that this system came into commercial use. At a time when damped waves having a frequency of 2 000 000 cycles per second or more were universally employed, Fessenden, with rare foresight, proposed the use of sustained waves of a frequency of 100 000 cycles or less produced by an alternator connected to an antenna of large capacity. And now, some twenty years later, all transoceanic stations are using the continuous wave system and relatively low frequencies advocated by him in 1900, and many of the largest of these stations use the radio frequency alternator. While great credit is undoubtedly due to the able designers who have produced sucessful radio frequency alternators, it should not be forgotten that the world is indebted primarily to Professor Fessenden for the high frequency alternator system of radio transmission. Not only was he the inventor of the system but also he was the first to put it into operation. The first high frequency alternator used for radio purposes was built for and put into operation by him in 1906.

The development of continuous wave transmission was greatly stimulated by the introduction of the Poulsen arc which was invented in 1903 by the eminent Danish engineer whose name it bears. The Poulsen arc is a remarkably simple and convenient source of high frequency for continuous wave transmission and is now made in sizes ranging from 2 to 1000 kilowatts (input) capacity. It is used in a majority of the continuous wave stations of the world at the present time, although it will probably be superseded in the future by the vacuum tube oscillator.

A special application of continuous wave transmission that is rapidly growing in importance is radio telephony. For this particular branch of radio we are also indebted to Prof. Fessenden who, in 1900, proposed the transmission of speech by means of continuously radiated waves modulated or varied in amplitude in accordance with speech waves. In the same year he actually transmitted speech for a distance of one mile and by 1907 he was able to transmit speech by this method for a distance of over one hundred miles.

Although damped wave or spark transmission has done and is doing good service, nevertheless, continuous wave transmission is destined to be universally employed in the future, except perhaps for emergency calls at sea. Its numerous advantages are dealt with in some detail in other papers in this issue. In view of its great

present importance and probable universal use in the near future, it is believed that continuous wave transmission may well be regarded as one of the fundamental and epoch-making inventions that has made modern radio possible.

It is but natural that the father of continuous wave transmission should also be the inventor of the best method of receiving undamped wave signals. Prof. Fessenden's classic "heterodyne" or beat method of reception is fully as important as his continuous wave transmission, for without heterodyne reception, many of the important advantages of continuous wave transmission are lost.

The forerunner of the heterodyne method was the system proposed by Prof. Fessenden in 1901 when he suggested simultaneously radiating continuous wave signals on two frequencies which differed from each other by a few hundred cycles. Interference or "beats" between these two waves produced an audible note at the receiving station, the frequency of which was equal to the difference in the frequency of the two waves sent out from the transmitting station. Some time later he conceived the idea of generating one of these high frequencies at the receiving station and there combining it with the received signal to produce beats of audible frequency. This is the method of reception that is now called the heterodyne method.

The heterodyne reception is so far superior to any other method of receiving undamped wave signals that its use may be regarded as indispensable in any modern station receiving continuous wave signals. Without heterodyne reception reliable transatlantic radio communication would be well nigh impossible. Heterodyne reception, therefore, may be regarded as another radio achievement of great and far reaching importance.

Simultaneously with the developments discussed above, many investigators turned their attention to the problem of improving the detector employed in radio reception. Innumerable detectors were proposed, each having its advocates. Coherers, magnetic detectors, electrolytic detectors and crystal detectors each had their day and eventually succumbed to the three electrode vacuum tube or "audion".

The history of the vacuum tube detector is an interesting one. Early in the eighties Edison discovered that current would pass between a hot filament and a cold plate sealed in an evacuated bulb if the filament were connected to the negative terminal of a source of current. J. A. Fleming investigated this so-called "Edison effect" and discovered in 1904 that a vacuum tube containing a hot filament and a cold electrode could be used as a radio detector. The detecting action was due to the well known rectifying action of such a tube. The Fleming detector never came into extensive commercial use. Its chief claim to distinction is the fact that it was the forerunner of the three electrode tube detector.

In placing a grid between the plate and filament of a Fleming detector, DeForest did far more than merely secure an improved detector. He produced a device that would *amplify*, that is, it would release energy from a local source in greater amount than the energy of the received signal. It is due to this amplifying action that the versatile three electrode tube is able to accomplish such remarkable results in the many applications that have been found for it.

For some years after its invention, the audion detector was of but little importance commercially. It was not more than twice as sensitive as the best crystal or electrolytic detectors and this slight gain in sensitivity was hardly sufficient to bring it into very extensive use. It was not until after Armstrong discovered that certain circuit connections enabled a three electrode tube to give signals many thousand times as strong as any other known detector that the vacuum tube began to assume its present great importance in the radio field. Because of its present importance and overwhelming potentialities for the future we may regard the three electrode tube as an invention that is second to none in the part it has played in the development of modern ratio.

Armstrong's discovery of the feed-back circuit that has assumed such great importance in our present day radio practice dates back to 1912. Coincident with the discovery of the enormous amplification possible with the feed-back circuit, he learned that proper adjustment of the circuit caused the three-electrode tube to produce continuous oscillations of radio frequency. He also found that, when generating such oscillations, the tube could be used to receive undamped waves by the heterodyne or beat method.

The generation of continuous oscillations by means of the feed-back circuit is now one of the most valuable applications of the three-electrode tube. As a local source of radio frequency for heterodyne reception it has no rival. The so-called "self-heterodyne" method of reception, in which the same tube is used as an oscillation generator and as a detector, is perhaps the most widely used method of receiving continuous wave signals.

For radio telephone transmission the vacuum tube oscillator is almost universally employed. In fact the present success of radio telephony may be said to be largely due to the feed-back oscillator, whose simplicity and ease of control make it peculiarly adapted to this service.

In the field of radio telegraph transmission also the vacuum tube oscillator seems destined to play an important part. As continuous wave transmission supersedes the spark system for short and medium range telegraph service, we shall find that the feed-back oscillator will be largely relied upon as a source of radio frequency for transmission purposes. Eventually the vacuum tube oscillator may even find its place in the high power transoceanic stations as a substitute for the alternator or Poulsen arc. Already one European station is feeding 75 kilowatts into its antenna from tube oscillators, using a battery of ten tubes, each having an output of

7.5 kilowatts. Even larger units have been built experimentally in this country and it will probably not be many years before we shall see vacuum tube oscillators having an output of 50 kilowatts and more.

The changes in radio practice brought about by the feed-back circuit are almost revolutionary in character. In the future it may be responsible for even more startling changes. In fact the feed-back circuit is at least equal in importance to the three-electrode tube whose value in the radio art it so greatly enhances. Armstrong's discovery, therefore, deserves a very high rank among the radio achievements of the present century.

There are many radio developments other than those discussed above that merit consideration in any paper that purported to be a complete history of the art. This article, however, merely attempts to set forth the fundamental discoveries that are largely responsible for the amazing progress in radio communication since the days when it first became a commercial possibility. This progress was largely based on the change from the old spark system to the modern, continuous wave transmission with heterodyne reception, and on the introduction of the two most valuable tools of the radio engineer, the three-electrode tube and the feed-back circuit.

Static Frequency Doublers

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Westinghouse Electric & Mfg. Company

In high power radio sending stations, where the power is supplied by a high frequency alternator, the sending frequency can be generated directly, or the required amount of power can be generated at a lower frequency, and then the frequency increased to the desired value by means of frequency multipliers.

The difficulties of constructing an alternator for, say, 15 000 cycles, are much less than those involved in constructing one for 30 000 to 60 000 cycles. This fact has prompted a careful study of frequency multipliers and resulted in their use in several of the high power radio stations. Some stations multiply to the extent of doubling three times, that is, they generate at 6000 cycles and double to 12 000, 24 000 or 48 000 cycles.

The possibility of using the variation in permeability of iron for frequency multiplying was suggested

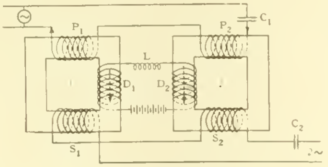

FIG. 1—HIGH FREQUENCY DOUBLER
Employing two identical transformers, each having three windings.

by Epstein, in 1902. The subject, however, was not given much study until 1911, when Joly and Vallauri developed several types of multipliers. There have been several satisfactory schemes devised for multiplying frequencies by means of saturated iron cores, but only the one that, in the writer's opinion, is the most economical will be discussed here.

Consider two identical transformers, each having three windings connected as shown in Fig. 1. The primaries, P_1 and P_2 are connected in series, and their outer leads are connected to an alternating-current generator. The secondaries, S_1 and S_2 and third windings, D_1 and D_2, are connected in series opposition. If an alternating voltage is impressed across the primary terminals, there will be identical magnetic flux variations in the two cores, with the result that no voltage will appear across the secondary terminals because this winding is connected in opposition. Now suppose a direct current is passed through windings D_1 and D_2, producing a magnetic flux in the two cores in the directions indicated by the dotted arrows. Under these conditions, when an alternating voltage is applied to the primary terminals, the magnetic flux variations in the two cores will not be identical, as the alternating flux will add to the direct-current flux in one core and subtract from it in the other. It is well known that the required number of ampere turns, magnetizing current

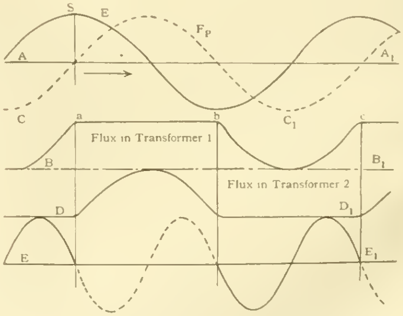

FIG. 2—FLUX WAVES OF HIGH FREQUENCY DOUBLER

per unit of flux, is much greater at high flux densities than it is for low flux densities. The alternating-current ampere-turns for the two cores are identical, being in series, therefore the increase in flux in core *1*, where the alternating and direct currents add, will be less than the decrease in flux in unit *2* where they subtract; consequently the flux variations in the two units will be different, resulting in there being a resultant voltage across the combined secondaries.

Let us investigate the voltage and flux conditions when the direct-current flux has completely saturated the cores. In Fig. *2*, A-A_1 is the zero line for primary voltage and flux; E represents the primary impressed voltage F_p represents the primary flux; B-B_1 is the zero line for the total fluxes in both cores; C-C_1 is the direct-current flux in transformer *1*, measured above B-B_1, and D-D_1 is the direct-current flux for transformer *2*, measured below B-B_1. The primary impressed voltage is assumed to have a sine wave E. Its resultant flux F_p will, therefore, be a sine wave 90 degrees later in time phase. The primary voltage has a maximum when its flux is zero, as indicated by point S. Starting from this point, for the next one-half cycle, the primary current will not materially increase the flux in transformer *1*, as this magnetic circuit is already saturated, but will produce a large decrease in flux in transformer *2*, as is indicated between points a and b. For the next half cycle, the conditions in the two cores will have reversed, as indicated between points b and c.

The voltage induced in the secondary windings due

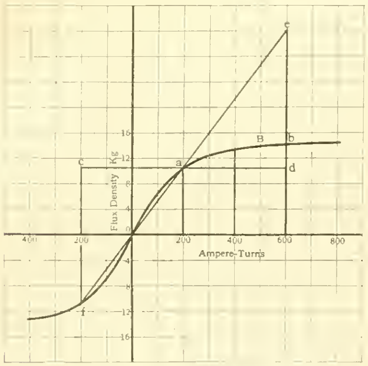

FIG. 3—EFFECT OF SATURATED CORE ON SHAPE OF VOLTAGE WAVE

to the change in magnetic flux in the two cores is shown in the lower part of Fig. *2*, with E-E_1 as zero line. Between the points a and b there is no change in flux in transformer 1, but there is a change in transformer *2*. The voltage due to this change is shown dotted. For the next half cycle, between points b and c, there is a change in flux in transformer *1* but not in transformer *2*. The voltage due to this change in flux is shown by a full line curve. This full line curve matches with the dotted curve at b, the two forming a continuous curve of voltage at double frequency. This double frequency voltage also appears across the direct-current winding, and in order to prevent a large double frequency current from flowing in the direct-current winding, an inductance, indicated as L in Fig. 1 must be inserted in this winding.

One or the other, or both cores, are highly saturated at all times, and the load currents in both primary and secondary windings must flow through the saturated inductance of the transformers. In order to offset this inductance, it is necessary to connect electrostatic condensers in both primary and secondary circuits, indicated as C_1 and C_2 in Fig. *1*. These condensers must store a large kv-a, several times the kw handled by the doubler. Large kv-a's can be economically handled by electrostatic condensers only at high frequencies. It is this large kv-a of condensers required that makes doubling commercial frequencies (25 and 60 cycles) impractical.

The analysis represented by Fig. *2* indicates that, if the primary and secondary windings have the same number of turns, their voltages will be the same. This, however, is not quite correct. The correct ratio of voltages can easily be determined, as outlined in connection with Fig. 3, in which B is the saturation curve of the cores. The absissæ represent ampere-turns, and the ordinates flux density. Assume that each transformer has a direct-current excitation of 200 ampere-

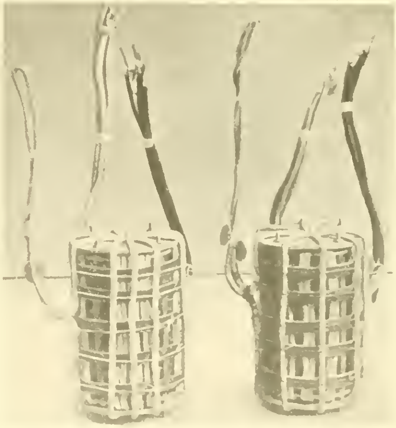

FIG. 4—HIGH FREQUENCY DOUBLER REMOVED FROM TANK

turns. Then with no alternating-current excitation, the cores will be excited to the point a, due to the direct-current ampere-turns. Also suppose that the maximum instantaneous alternating current ampere-turns will be 400, then as the alternating-current ampere-turns start from zero, the two cores will each start at a. One will increase to the sum of the alternating-current and direct-current turns, or 600, shown at b, while the other will decrease to the difference between the alternating-current and direct-current turns or −200, as indicated at f. The flux in the one core will have changed from a to f, or a value cf, while the other core will have changed from a to b, or a value bd. The total variation affecting the primary voltage will then be $cf + bd$, while the variation producing the secondary voltage will be $cf - bd = be$. Thus the secondary voltage is less than the primary by twice bd.

Continuous Wave Radio Communication

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THE USE of continuous or undamped waves in radio communication is rapidly becoming universal to the exclusion of damped wave or spark systems. It is highly significant that the Preliminary International Communications Conference which convened at Washington in October 1920, recommended legislation which will confine the use of damped wave equipment to low power ship emergency installations and amateur sets operating on short wave lengths. In all probability, the next five years will witness the replacement of practically all existing spark apparatus with continuous wave equipment. It may not be too much to predict that even amateur communication on wave lengths as short as 200 meters, where beat note reception offers the greatest difficulties, will become largely continuous wave, reception of these short wave lengths having been made possible by means of the Armstrong superaudodyne method.

The reasons for the discontinuance of spark apparatus in favor of continuous wave equipment are numerous. In the first place the increasing use of radio communication makes interference between stations a serious problem. The wave lengths used in radio communication lie between 150 and 25 000 meters corresponding to frequencies of 2 000 000 to 12 000 cycles per second*. The longer wave lengths, from 10 000 meters upwards, are employed for transoceanic work and the shorter in ship to ship, ship to shore, and land station operation. It is impossible to operate two or more damped wave stations in the same locality on wave lengths closer than three percent to each other without having interference, even if these stations have decrements as low as 0.06 which is an extremely sharp spark wave. A receiving station attempting to copy one of these transmitting stations could not help hearing and being interfered with by others. The number of damped wave transmitters it is possible to work in a given locality is thus limited to a small number. The wave lengths of continuous wave transmitters may be adjusted to within one percent of each other and yet cause no interference at a distant receiver. With further refinements in receiving apparatus, such as tuned audio-frequency circuits, even closer wave lengths may be used. It is possible to handle at least three times as much traffic in a given area with continuous wave apparatus as with damped wave transmitters.

The heterodyne or beat method of reception invented by Professor R. A. Fessenden, in 1905, when employed in connection with a vacuum tube oscillator and detector, is by far the simplest and most sensitive means of receiving continuous wave signals. The heterodyne system consists simply in combining the incoming radio frequency waves with a current of a frequency differing from the incoming signal by an audible frequency amount, the result after rectification being the audio frequency. By adjusting the frequency of the local oscillator at the receiver it is easily possible to make the beat any desirable frequency, thus allowing the operator to utilize the most sensitive frequency for the telephone receivers, tuned amplifier or recorder.

In addition to lessened interference and beat note reception, the lower voltages on continuous wave transmitting apparatus should be taken into consideration. For example a three kw, 500 cycle spark transmitter operating at 1000 meters wave length on an antenna of 0.001 micro farads capacity and six ohms resistance might put 1000 watts into the antenna. The instantaneous maximum voltage on the antenna would be approximately 45 000 volts. A continuous wave set with the same power output would give a maximum antenna voltage of only 10 000 volts; which is a big advantage as regards antenna insulation, as well as on the set itself. This is obviously the case since, with a spark set, the antenna and oscillating circuits have power in them for only short intervals of time, separated by relatively long periods of inaction, while in the continuous wave system power is in the oscillating circuits continuously. There are other advantages to con-

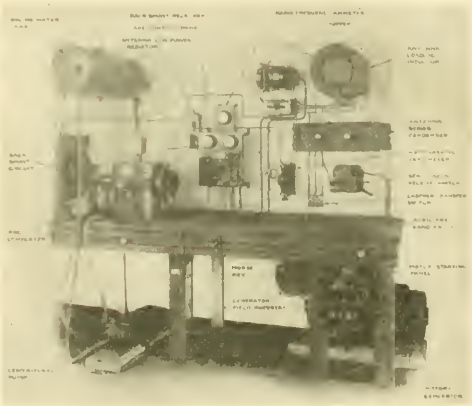

FIG. 1—2 KW POULSEN ARC TRANSMITTER
Built for the United States Navy by the Federal Telegraph Company.

*For those not familiar with radio nomenclature it may be said that the term "wave length", is generally used in place of "frequency" the relation between the two being:—*wave length* $= \frac{3 \times 10^8}{frequency}$

tinuous wave apparatus, not the least of which is the lack of noise, especially in ship installations, where the noisy spark has been so disturbing to passengers.

On the other hand, the most important advantage of continuous wave systems, namely less interference, becomes a disadvantage when it is desired to broadcast or to send out distress signals. The sharpness of the tuning makes continuous wave signals more difficult to pick up than spark signals. This disadvantage will gradually disappear, however, as continuous wave sets working on short wave lengths, say 300 to 2000 meters, come into general use.

The pioneer inventor in the field of continuous wave radio communications is Professor Fessenden. As early as 1901, he proposed the use of continuous or sustained waves of a relatively low frequency of 100 000 cycles or less, generated by radio frequency alternators. At the same time Prof. Fessenden pointed out the desirability of employing large antenna for long distance work in place of the relatively small high antenna in use at that time. Prof. Fessenden also noted that radio speech transmission could best be accomplished by modulating the output of a source of continuous waves. It is remarkable to note how closely the radio systems of today follow the lines suggested by Prof. Fessenden twenty years ago.

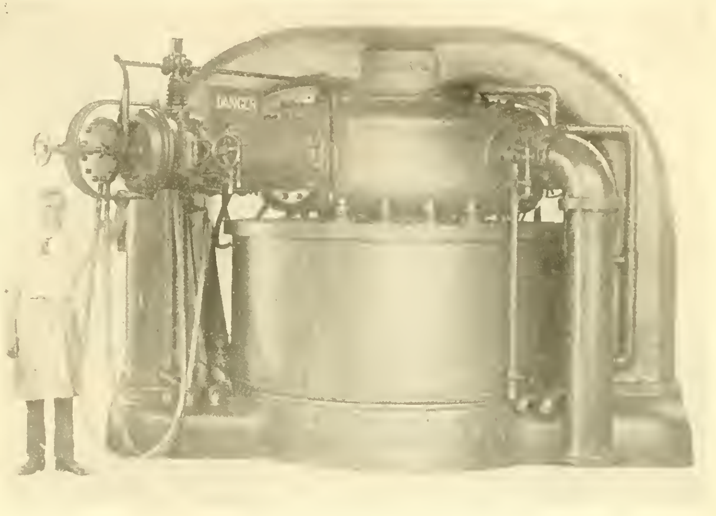

FIG. 2—1000 KW ARC CONVERTER

Built for the United States Navy. Two of these converters were installed at the Lafayette Radio Station near Bordeaux, France.

Continuous or undamped wave generators of radio frequencies may be divided into three classes; first the arc generator or arc converter, second the high frequency alternator and third the hot cathode vacuum tube. Other systems operating upon spark principles but generating waves of very slight decrement employ the timed spark and the Chaffee gap.

ARC GENERATORS

It was early discovered by Elihu Thomson that an arc between carbon electrodes would "sing" when shunted by a capacity and inductance of proper values. On account of its falling current-voltage characteristic, the arc generated oscillations in a circuit consisting of capacity, inductance and arc which, with the constants used, were generally of an audible frequency, hence the name "singing arc". It is doubtful, however, if the arc between carbon electrodes in air employed by Thomson would have been capable of generating oscillations of much higher than audio frequencies. During the period from 1900 to 1903, W. Duddell and V. Poulsen developed the arc to the point where radio frequencies could be generated. Poulsen enclosed the arc in a hydrocarbon atmosphere, made the anode of copper water-cooled and placed the arc in a strong transverse magnetic field*.

Arc converters are now built in sizes of 2 to 1500 kw input at 400 to 1250 volts direct current with efficiencies of 20 to 30 percent. Signaling has generally been accomplished by short-circuiting a part of the inductance in the antenna circuit, thus changing the wave length transmitted and the pitch of the signal at the receiving station. This compensating or "back wave" method has been prohibited in the recommendations of the Preliminary International Communications Conference as causing unnecessary interference. The most successful method of sending a single frequency is that invented by Lt. W. A. Eaton of the United States Navy, in which the arc load is shifted alternately from the antenna to a phantom load circuit. For telephone transmission, the arc may be modulated by placing a microphone in the antenna circuit, or in a circuit coupled to the antenna circuit. It is also possible to re-ignite the arc for each dot or dash signal by passing a spark between the electrodes. Fig. 1 shows a typical two kilowatt converter with motor-generator set and control equipment such as are used by the U. S. Navy for ship installations. The largest arc converters now in operation are the two 1000 kw units installed at the Lafayette Radio Station near Bordeaux, France.

*These improvements cover substantially the arc converter or arc generator as built at present by the Federal Telegraph Company and the Westinghouse Electric & Mfg. Company, under Poulsen patents in the United States.

HIGH FREQUENCY ALTERNATORS

The first alternator designed to give a frequency higher than the usual 60 to 133 cycles was built by Elihu Thomson and Nikola Tesla in 1890. This machine was not for radio purposes, however, but for arc lighting, there being considerable objection at that time to the hum produced by the low frequency arc. A frequency of 100 000 cycles per second or near the upper limit of audibility was claimed for the machine.

During 1902, B. G. Lamme, of the Westinghouse Company, designed a high frequency alternator. This machine was of the double crown inductor type similar to modern high frequency alternators of today. This alternator was used in experiments on wired wireless and multiplex telephony by M. Le Blanc in France.

In 1900, Prof. Fessenden, then in the employ of the United States Government, asked Dr. C. P. Steinmetz of the General Electric Company if it would be possible to build a Mordey induction-type alternator for a frequency of 100 000 cycles. Not favoring this type of machine for high frequencies, Dr. Steinmetz suggested awaiting the results from a 10 000 cycle, two kw alternator which they were building. This machine was completed in the fall of 1902 and used experimentally for radio telephony by Prof. Fessenden. In 1904 the question of higher frequency alternators was taken up again with the General Electric Company, who agreed to build a 100 000 cycle machine of the induction type proposed by Prof. Fessenden. The development of the alternator was started by Mr. Ernest Berg, but this work was turned over to Mr. E. F. W. Alexanderson, who continued working on this machine in connection with Prof. Fessenden until the summer of 1906, when the machine was tested and shipped to the Brant Rock station of the National Electric Signaling Company. Here it was used for continuous wave telegraphy and modulated continuous wave telephony. Prof. Fessenden himself subsequently built a double armature alternator having 150 teeth in the field and 300 coils on each armature. This unit was direct-connected to a De Laval steam turbine and generated 2.5 kw at 225 volts and 72 000 cycles per second. In 1908 Prof. Fessenden transmitted speech from Brant Rock, Mass. to New York City, a distance of 290 miles, by means of a high frequency alternator. The power in the antenna was 200 watts and the carrier frequency was 100 000 cycles per second.

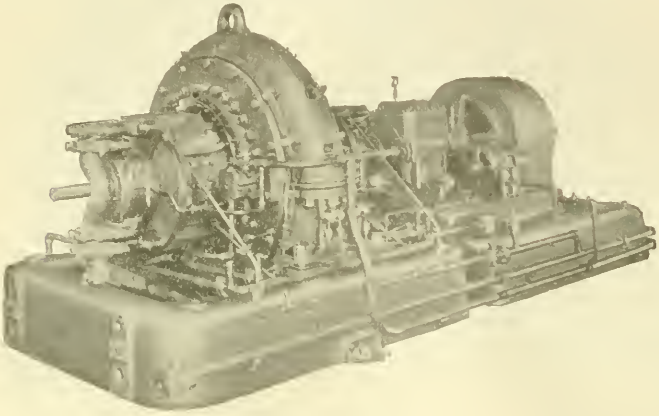

FIG. 3—200 KW HIGH FREQUENCY ALTERNATOR
With 600 hp driving motor.

A modern type of high frequency alternator, extensively used by the Radio Corporation of America for long distance communication* is shown in Fig. 3. This is an inductor machine having stationary field and armature windings, with a toothed disc rotating in the magnetic field. This type of alternator has been manufactured in sizes up to 200 kw for frequencies varying from 100 000 cycles in the two kw size up to 25 000 cycles in the 200 kw machine. Efficiencies of 20 to 40 percent are claimed. A magnetic amplifier, controlling the field circuit of this high frequency alternator, has been developed, by the aid of which speech may be transmitted.

A Latour high frequency alternator, which is similar in construction to the early design by Mr. Lamme, is installed at the Lafayette radio station, in addition to the two 1000 kw arc converters. A high frequency alternator of the same general type but of somewhat different construction has been developed by the Westinghouse Company. The German station at Eilviese is equipped with an alternator of the reflection type built by Goldschmidt.

VACUUM TUBES

The use of a hot cathode rectifier employing the so-called "Edison effect" as a radio detector was discovered in 1904 by Dr. J. A. Fleming. Dr. Fleming's valve was simply a rectifier having a heated filament or cathode and a plate or anode placed in an evacuated bulb. It was used as a detector in receiving and was a great improvement as regards stability of adjustment over the detectors in use at that time. At a somewhat later date Dr. Lee De Forest made a much superior detector by placing a grid or control member between the filament and plate in the bulb. This vacuum tube or audion valve, as it was called, was placed upon the market previous to 1907 and was the forerunner of the three electrode vacuum tube of today.

It remained for Armstrong in 1912 to invent the feed-back or regenerative circuit by means of which the three electrode vacuum tube may be made to amplify to an enormous degree and to generate alternating cur-

*This machine is described fully in the *General Electric Review*, October 1920, p. 813.

rents of almost any desired frequency. The tubes used by Armstrong were of the high vacuum or "hard" variety in contrast to the low vacuum or soft audion

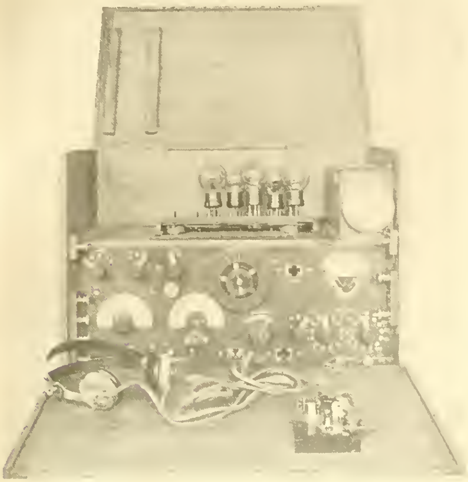

FIG. 4—FRENCH E-13 CONTINUOUS WAVE VACUUM TUBE TRANSMITTING AND RECEIVING SET

valves made by Dr. De Forest. The soft tube is a more sensitive detector but it was noted by Armstrong that only hard tubes could be used as power oscillators or could be depended upon as amplifiers.

Armstrong's contributions to the art of continuous wave radio communication are thus of the greatest importance. First, his invention of the feed-back circuit is fundamental to the operation of vacuum tube transmitters. Second, the reception of continuous waves by the heterodyne method is greatly simplified by using a vacuum tube as a local oscillator with the receiver, in place of a small arc or generator or, in the case of short waves, by Armstrong's self-heterodyne or oscillating detector. For extremely short waves the Armstrong superheterodyne detector and amplifier is a practical necessity.

In 1913 the American Telephone & Telegraph Company and Western Electric Company started development of three electrode tubes as amplifiers for telephone repeater work and oscillators to generate the high frequency carrier wave for multiplex telephony. Some very creditable work was accomplished by the engineers of these companies so that by 1917 high vacuum tubes, that could be used to generate small amounts of radio frequency power, were available.

Soon after the outbreak of the war in 1914, France developed and put into the field an innovation in military radio apparatus, namely continuous wave transmitting and receiving sets using three electrode tubes as oscillators for transmitting and the same type of tube as self-heterodyne or oscillating detector and audio frequency amplifier for receiving. Fig. 4 shows a late type of French vacuum tube transmitter and receiver. These sets were small, compact and light in weight, yet it was possible to establish telegraphic communication of from 50 to 100 miles with only 5 to 10 watts output on low portable field antennae. This illustrates the seemingly remarkable carrying power of continuous wave transmission, due to the fact that all the energy radiated at the transmitter is on one wave length only, the absolutely pure musical tone received by means of the heterodyne, adjustable in pitch at the receiver, and the increased sensitiveness of the detector when using the heterodyne method.

The British army brought out similar continuous wave apparatus shortly afterward, using at first the standard French vacuum tubes, and later manufacturing their own tubes. With the entry of the United States into the war, development of vacuum tube telegraph and telephone sets was immediately started by the Signal Corps and the Navy. The Signal Corps sets were designed for tubes manufactured by the Western Electric Company. Fig. 5 shows a Signal Corps

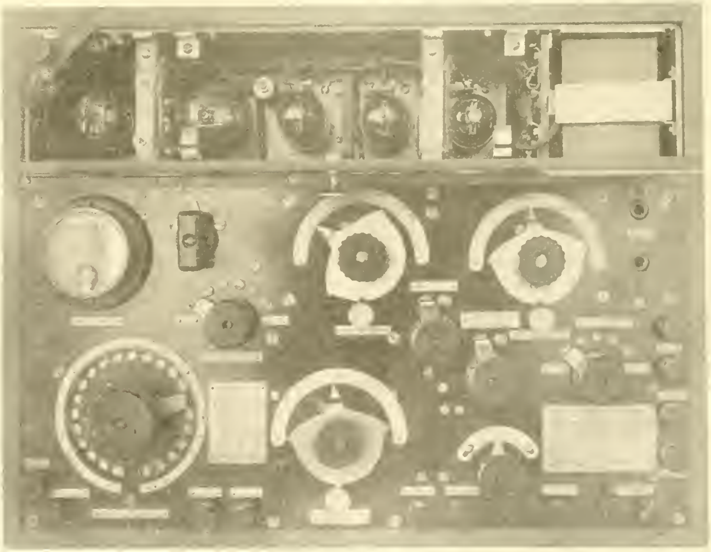

FIG. 5—U. S. SIGNAL CORPS CONTINUOUS WAVE RADIO TRANSMITTER AND RECEIVER TYPE S C R 70

continuous wave transmitter and receiver (Type SCR 79). The Navy seemed to favor tubes developed by the General Electric Company. Both of these companies now have standard tubes of 5, 50 and 250 watts. When greater power is desired it is customary to connect one or more tubes as master oscillators or exciters and to amplify the output of these tubes by banks of similar tubes in parallel, having their grids connected to the output of the exciters and their plates to the output circuit of the set. Fig. 6 illustrates a set of six kilowatt input built by the English Marconi Company. The high voltage direct current for the plates is obtained from alternating current by means of the four rectifying tubes, shown at the right. Two control and two modulating valves for telephony are mounted between the rectifying tubes and the six oscillator tubes at the left. The antenna loading inductance is mounted separately.

The relative advantages and disadvantages of the three types of continuous wave generators, the arc, the alternator and the vacuum tube are as follows:—

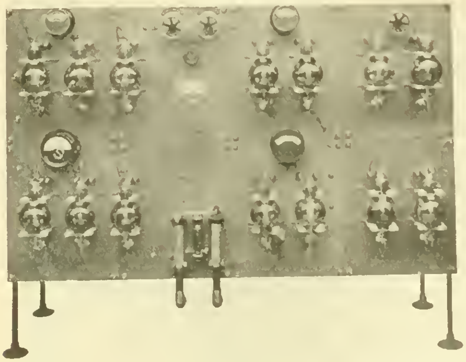

FIG. 6—SIX KW MARCONI CONTIOUOUS WAVE TRANSMITTER

The advantages of the arc lie chiefly in the low first cost, rugged construction and low cost of operation and maintenance. The wave length generated may be easily adjusted by varying the antenna loading inductance or, for short wave lengths, the series antenna condenser. With the present design of arcs, however, wave lengths shorter than 1000 meters, (300 000 cycles) are not commercially practical. Also arc transmitters radiate harmonics of the fundamental frequency which cause much interference at nearby receiving stations. Despite these disadvantages, at least 90 percent of all the continuous wave stations are now equipped with arcs. They are standard equipment on the larger ships and in the land stations of the United States Navy.

The high frequency alternator system has the advantage of emitting a practically pure continuous wave without harmonics, easily controlled by means of the field current of the generator. The mechanical details have been worked out so that but little more attention is required than for low-frequency alternators. While alternators may be designed to give any frequency less than about 200 000 cycles, a given machine cannot generate a frequency materially different from that for which it was designed. This is fundamentally true, since the frequency and the output both are directly proportional to the speed of the rotor. Economical design calls for a working speed but little less than the safe maximum speed allowed while, if it is desired to lower the frequency, the output falls off in the same proportion. Speed regulation is very important, particularly when heterodyne reception is used, because any small change in speed affects the wave length and hence the audio frequency beat note at the receiver. For high power long distance stations where transmission is always on the same wave length, however, the alternator seems well suited.

The vacuum tube possesses most of the advantages of both the arc and the alternator, as a generator of high frequency power. It generates a pure continuous wave, without harmonics, which can be easily controlled for telegraphy by several different methods or modulated for telephony and interrupted continuous wave telegraphy. To change the wave length it is only necessary to adjust the master oscillator or exciter to the value desired and tune the antenna to this wave length. It is common practice to employ several power amplifier tubes in parallel when high powers are desired. It thus becomes possible to replace defective tubes by cutting them out of circuit without stopping transmission nor seriously overloading the remaining tubes. The power output may be similarly changed to transmit readily over varying distances. Altogether the vacuum tube provides the simplest and most flexible means of generating high frequency power. At the present time the output of the vacuum tube sets does not compare with the arc or the alternator, largely due to the high price of the tube and its comparatively small power output. Tubes of ten kilowatts output have been made and operated while tubes of 20 kilowatts and larger are under development. By using a number of these large tubes in parallel it will be possible in the near future to build vacuum tube transmitters equivalent in output to the arc and alternator. The power supply to the plate circuit of the large tubes will probably be direct current at 10 000 to 50 000 volts obtained through hot cathode or mercury arc rectifiers, from high voltage alternating current supply. Tube efficiencies of 50 to 70 percent will be obtained.

In this connection the recommendations of the Imperial Wireless Telegraphy Committee of England appointed to investigate and recommend a system of radio communication for England and her colonies, will be of interest. More than a year was spent in carefully examining records and visiting arc, alternator and tube stations then in operation. After due deliberation the committee reported in favor of employing vacuum tube transmitters entirely as the only system which could be relied upon to give reliable service at a reasonable expense.

In conclusion, continuous wave systems of radio transmission are rapidly replacing the damped wave or spark systems. In the case of transoceanic stations, this has already taken place and will within a few years occur also in the case of ship to shore and overland service. This will be true because continuous wave systems give the greater distance of communication per dollar of investment (a fact which will finally determine the system to be used) and at the same time allow a greater number of communications to take place simultaneously. At the present time arc converters are used in all powers from 2 to 1000 kw. The high frequency alternator is used mainly for transoceanic communication. The vacuum tube seems destined ultimately to replace both the arc and the alternator, having the electrical advantages of both and the disadvantages of neither.

Why High Frequency for Radiation?

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WHEN asked to write a paper on this subject, the author was considerably nonplussed. Beginning with Maxwell who laid the foundation, and followed by numerous other mathematical physicists, most notably Lorenz who introduced his beautiful and most useful retarded potentials, the literature abounds in integral signs, partial differential equations and the symbols of vector analysis. Was it possible to explain the theory of Maxwell and its consequences in ordinary English, when all the refinements of higher mathematics have served to trace these consequences in detail in only a few simple cases?

In the following discussion, the author has attempted to show, in a qualitative way only, how the introduction of Maxwell's displacement currents, combined with the previously held laws of electromagnetism, explain the fact that electric and magnetic fields are propagated with a finite velocity, and how it is that a rapidly varying current continually gives out energy to space. As a beginning a review is given of the laws of electromagnetism previous to Maxwell, which are practically the electromagnetism of the electrical engineer of today.

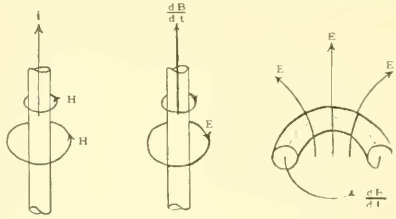
PRE-MAXWELLIAN ELECTROMAGNETISM

An electric current is always surrounded by a magnetic field, the lines of force of which form closed loops encircling the current. The magnetomotive force around a loop, that is, the length of the loop multiplied by the average magnetic force along it, is proportional to the total current enclosed by the loop, the factor of proportionality depending on the kind of units used. Fig. 1 (a) shows the case of a portion of a long straight conductor, where I is the current, and H the magnetic force.

FARADAY'S LAW OF INDUCTION

Faraday discovered that a *varying* magnetic flux surrounds itself with a field of electric force in a manner entirely similar to the way a continuous current surrounds itself with a field of magnetic force. The direction of the loops, however, is opposite. Fig. 1 (b) shows the field set up by an increasing long straight magnetic flux. This might represent, for example, a leg of a core type transformer. $\frac{dB}{dt}$ stands for the rate of change of magnetic flux and E for the electric force. The electromotive force around a loop, that is the length of the loop multiplied by the average electric force along it is proportional to the rate of change of flux enclosed by the loop, the factor of proportionality depending on the units used. This electromotive force is the e.m.f. per turn of the transformer engineer.

It is desirable, for the sake of the examples to be taken up further on, to consider the electric field pro



(a) (b) (c)

FIG. 1 (a)—MAGNETIC FIELD PRODUCED BY A CURRENT FLOWING IN A LONG STRAIGHT CONDUCTOR

FIG. 1 (b)—FIELD SET UP BY AN INCREASING LONG STRAIGHT FLUX

FIG. 1 (c)—FIELD PRODUCED BY A VARYING CLOSED LOOP OF FLUX

duced, not by a long straight varying magnetic flux but by a varying closed loop of flux. This is shown in Fig. 1 (c).

PRE-MAXWELLIAN RISE AND FALL OF CURRENT

Let us see what these two field relations give when applied to the following example. In a long straight conductor, let the current start at zero, and begin increasing at a definite rate. After a certain time, let it stop increasing and remain constant for a while, and then let it decrease at a constant rate to zero again. The graph of this is shown by the curve I, Fig. 2. The relation between the current and the magnetic field described above, when applied to this example, requires

that a magnetic field such as that pictured in Fig. 1 (a) spring up at once throughout all space on the first appearance of current, and increase in strength proportionally with the current. When the current stops increasing, the magnetic field everywhere must stop increasing; when the current decreases, the magnetic field everywhere must decrease and, when the current becomes zero, the magnetic field must have disappeared everywhere. Thus, according to this theory there is no finite propagation time, but the magnetic force at any point, however distant, instantly takes a value corresponding to whatever current is flowing in the conductor.

The second relation, Faraday's law of induction, shows that, during the *rise* of current, a field of electric force is set up. Studying Fig. 1 (c) and applying it to this example, we get the field shown in Fig. 3. Near the conductor, the lines of electric force are parallel to the current, but in the opposite direction. Inside the conductor, the electric field forms the counter e.m.f. of self-induction of the electrical engineer. Curve *E*, Fig. 2, shows the electric force due to the current in conductor. According to this theory, the electric field

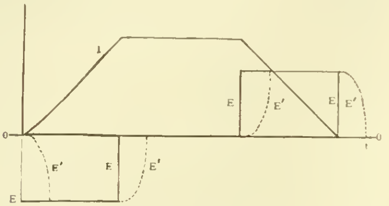


FIG. 2—EFFECT OF MAXWELL'S DISPLACEMENT CURRENTS ON RADIATION OF POWER

springs full fledged to its proper value the instant the current begins to rise, and disappears instantly when the current stops increasing.

During the period when it is increasing, the current does work, represented at each moment by the product of *E* and *I*, Fig. 2. When decreasing, the current has work done on it at a rate given by the same product. These two amounts of work are evidently equal. According to the Pre-Maxwellian theory, the first represents the storing of energy in the magnetic field, and the second its complete return to the conductor. Thus, in the Pre-Maxwellian theory, there is no room for radiation. Whatever energy is given up to space when a current increases is not lost, but is stored there as magnetic energy, ready to be returned, years later perhaps, when the current decreases.

WEAKNESS OF THE PRE-MAXWELLIAN THEORY

Although the Pre-Maxwellian theory does not fit the facts for high frequencies, it does come very close to the truth for currents of moderate frequency. Were this not so, the present-day education of our 60 cycle engineers would have to be considerably modified. Since Maxwell had no knowledge of high-frequency phenomena, it is interesting to speculate as to what it was that he found unsatisfactory in the theory as then developed. Probably he found greatest difficulty in accepting the theory of immediate response of the magnetic field at any point, to changes in a distant current. Possibly also the instantaneous rise to finite values of the electric field, as shown above, was not compatible with his ideas of energy stored in an electric field. These difficulties were entirely removed by his hypothesis as to displacement currents. The subsequent experimental confirmation by Hertz of the consequences of this hypothesis put it on as firm a basis of fact as the other laws of electromagnetism.

MAXWELL'S DISPLACEMENT CURRENT

Just as a varying magnetic flux surrounds itself with an electric field, so a varying electric flux surrounds itself with a magnetic field. This is the new law of electromagnetism introduced by Maxwell. An increasing electric flux produces a magnetic field in all respects like a conduction current, as shown in Fig. 4.

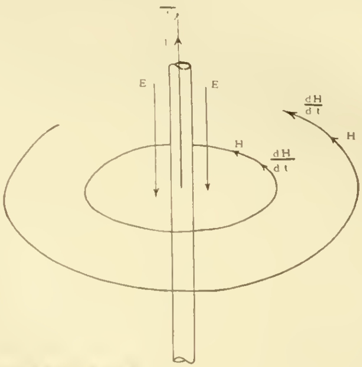


FIG. 3—FIELD OF ELECTRIC FORCE SET UP DURING THE RISE OF CURRENT

Hence the name "displacement" current which Maxwell gave to varying electric flux. We must now modify our previous statement and say that the magnetomotive force round a loop is proportional to the total current enclosed, conduction plus displacement currents.

MAXWELLIAN RISE AND FALL OF A CURRENT

Consider now how the introduction of the magnetic effects of the displacement current alters the fields produced by the rising and falling current considered before. Consider the average electric force in an annulus surrounding the conductor, and of the same area as the conductor cross-section, Fig. 5. The electric force cannot rise instantly to a finite value as in the Pre-Maxwellian theory. In fact, the rate of rise of electric force in this annulus must be less at any moment than the conduction current. For, if it were equal to the conduction current, since it is oppositely directed, the total current, conduction plus displacement would be zero, and there would be no magnetic field at a radius greater than that of the annulus. The rise of the electric field near the conductor, therefore, follows a curve

like the dotted one shown in Fig. 2. Actually, at the first instant, when the conduction current is small, the displacement current in the annulus equals the conduction current and the magnetic field at the rim of the annulus is zero. This transient condition, quickly passes as the conduction current rises. At a greater distance from the conductor, because of the greater area looped by magnetic lines and therefore the larger section over which displacement current is to be integrated, the total displacement current stays equal to the conduction current for a longer time, so that the magnetic force at that point does not begin to rise until some time after the conduction current started. In other words, at any instant, the magnetic field reaches out to such a radius that the displacement current within that radius equals the conduction current. Beyond that radius at that moment there is no field. We thus arrive at a finite rate of propagation of the field set up by the current.

Just as the electric force at the conductor rises gradually and not instantaneously when the current begins to change, so also the electric force falls off gradually and not instantaneously when the current stops changing. The complete curve for the electric force at

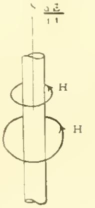


FIG. 4—MAGNETIC FIELD DUE TO INCREASING FLUX

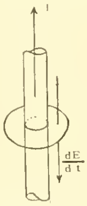


FIG. 5—ELECTRIC FORCE SURROUNDING THE CONDUCTOR

the conductor is given by the dotted curve E', of Fig. 2. Let us compare this with the full line curve E, showing the counter e.m.f. of self-induction according to the Pre-Maxwellian notions. We see that E' is smaller than E at the start when I is small, and that E' is larger than E for a short interval after I attains its constant maximum value. Hence, in building up the current I from zero to its full value, Maxwell's theory requires a greater expenditure of work than called for by the older theory. Again, when the current begins to decrease, E' is less than E; and it is not until I is zero that E' is greater than E and $E'I$ becomes zero or has no energy value. Hence Maxwell's theory returns less energy to the circuit when the current decreases than the older theory. Hence, as a net result of bringing the current up and then down again, energy has been lost to the medium carrying the electric and magnetic fields. In other words, energy must be radiated into space.

Studying the curves of Fig. 2, it is seen that the curve E' lags or is delayed in time over E. It is fairly clear, that if I was an alternating current, E and E' would be alternating quantities, and E, the counter e.m.f. of self-induction according to the older theory, would be in time quadrature with I. The true counter e.m.f. E' would, therefore, lag behind the quadrature position. The electromagnetic reactions on an alternating current, therefore, have not only a component of e.m.f. in quadrature with the current, corresponding to the self-induction of the circuit, but also a component of e.m.f. opposite in phase to the current, corresponding to the so-called radiation resistance.

WHY HIGH FREQUENCY?

We are now able to answer the question of the paper. Without the displacement currents, we would have no radiation. In proportion as the displacement currents play a greater part in determining the magnetic field, more energy is lost to space by an alternating current. Now the displacement current is proportional to the rate of change of electric force, and the electric force is proportional to the rate of change of the current. Hence, the more rapidly the current alternates, the greater will be the relative proportion of displacement current to conduction current. In fact, since a double differentiation is involved, the radiation will vary as the square of the frequency.

WHY RADIATE?

Why not let a sending circuit act directly on a receiving circuit by transformer action, or mutual induction, in the manner familiar to the electrical engineer? A comparison of the force at a distance produced by the two types of field provides the answer.

Formulae for the field produced by a steady current in a finite circuit show that the magnetic force at great distances varies inversely as the ~~third~~ 2nd power of the distance. What is the law for radiated fields? In this case, the radiated energy spreads out in spherical waves. Since the total energy in a wave stays constant as the wave spreads out, the energy density must vary inversely as the area of the wave front, and therefore inversely as the square of the radius. The energy density, however, is proportional to the square of the magnetic force. Hence the magnetic force in a radiated field varies inversely as the first power of the distance. For great distances this gives an enormous advantage over the inverse square ~~cube~~ law for steady fields.

While it has been shown that for a given current, the higher frequencies give out more power as radiation, it does not follow in all cases that the highest frequencies are the best for radio transmission. Radiation given off by a transmitting station must pass through the air and over the earth to the receiving station. During this passage, it loses energy due to the currents induced in the earth and in ionized strata of the atmosphere. It has been found experimentally that the energy loss of this nature increases with the frequency. Hence for transmission to great distances it has been found more practical to use lower frequencies, (3000 to 10 000 meters), even though greater antenna current is necessary to radiate a given energy.

Data and Tests on 10 000 Cycle Per Second Alternator

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Westinghouse Electric & Mfg. Company

THE FOLLOWING ARTICLE is slightly condensed from a paper the author presented before the American Institute of Electrical Engineers in May 1904, a year or so after the machine described was built and tested. It is reproduced here because, as explained in an editorial in this issue, this early machine represents such a complete anticipation of recent practice, at least one alternator along very similar lines being in use for transoceanic radio work, while others are contemplated. The close similarity between these modern high-frequency machines and the one which was designed in 1902, gives striking evidence of the clear insight into correct principles which governed the original design. (Ed.)

THE STARTING POINT in this machine was the sheet steel to be used in the armature. No direct data were at hand showing losses in sheet-steel at such high frequencies, nor was there at hand any suitable apparatus for determining such losses. As preliminary data, tests at frequencies up to about 140 cycles per second were used, and results plotted for different thicknesses of sheet steel. Also, tests were obtained showing the relative losses due to eddy currents and hysteresis, and these were plotted, taking into account the thickness of the sheets. These data were not consistent throughout; but the general shape of the curves was indicated, and in this way the probable loss at the frequency of 10 000 cycles per second was estimated for the thinnest sheet steel obtainable. The steel finally secured for this machine was in the form of ribbon about 2 in. wide, and about 0.003 in. thick, which was much thinner than steel used in commercial dynamos or transformers, which varies from 0.125 to 0.0280 inch. Therefore the machine had to be designed with the intention of using this narrow ribbon of steel for the armature segments.

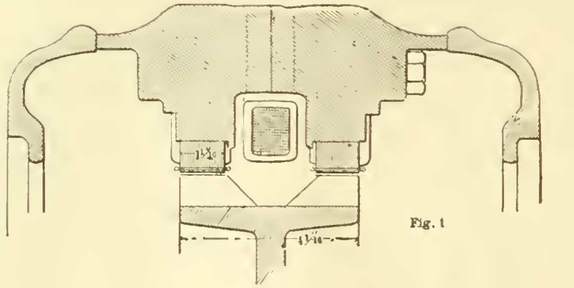


Fig. 1

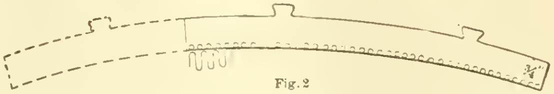


Fig. 2

A second consideration in the construction of such a machine is the number of poles permissible for good mechanical construction. For instance, at 3000 r.p.m. —which was adopted as normal speed—the number of poles is 400 for 10 000 cycles per second. The frequency, expressed in terms of alternations per minute, multiplied by the pole pitch in inches, gives the peripheral speed in inches. At 1 200 000 alternations per minute (or 10 000 cycles per second) and a pole pitch of 0.25 in., for example, the peripheral speed of the field will be 25 000 feet per minute. Thus it was evident that either a pole construction should be adopted which would stand this high peripheral speed, or the pole-pitch should be less than 0.25 in. It was finally decided that an inductor type of alternator would be the most convenient construction for this high frequency. With the inductor type alternate poles could be omitted, thus allowing 200 pole projections, instead of 400. The field winding could also be made stationary instead of rotating, which is important for such a high speed. This construction required a somewhat larger machine for a given output than if the usual rotating type of machine were adopted; but in a machine of this type where everything was special, the weight of material was of comparatively little importance, and no attempts were made to cut the weight or cost of the machine down to the lowest possible limits.

The following covers a general description of the electrical and magnetic features of the machine:—

ARMATURE

The armature was built up in two laminated rings dovetailed into a cast-iron yoke, as indicated in Fig. 1. The laminations were made in the form of segments dovetailed to the cast-iron yoke, Fig. 2. Special care was taken that the laminations made good contact with the cast-iron yoke, as the magnetic circuit is completed through the yoke.

The armature sheet steel consisted of plates of 0.003 in. thickness. The sheet steel was not annealed after being received from the manfacturer; it was so thin that to attempt annealing was considered inadvisable. To avoid eddy currents between plates each segment was coated with a thin paint of good insulating quality. This painting was a feature requiring considerable care and investigation, as it was necessary to obtain a paint or varnish which was very thin, and which would adhere properly to the unannealed laminations. These laminations had a bright polished appearance quite different from that of ordinary steel. They

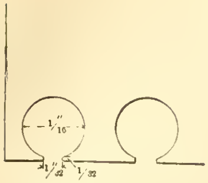


Fig. 3

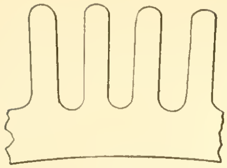


Fig. 5

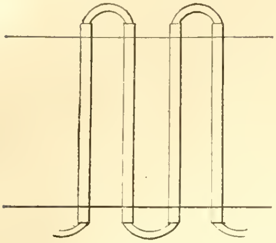


Fig. 4

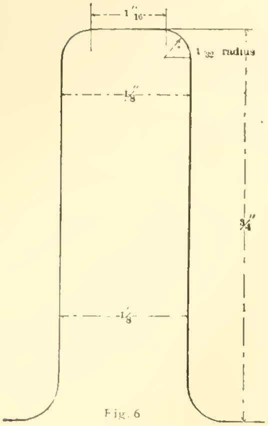


Fig. 6

were so thin that the ordinary paint or varnish used on sheet steel made a relatively thick coating, possibly almost as thick as the plates themselves. A very thin varnish was finally obtained which gave a much thinner coating than the plate itself, so that a relatively small part of the armature space was taken up by the insulation between plates.

Each armature ring or crown has 400 slots. Each slot is circular and 0.0625 inch diameter, Fig. 3. There is 0.03125 inch opening at the top of the slot into the air-gap, and the thickness of the overhanging tip at the thinnest point is 0.03125 inch. The armature winding consists of No. 22 wire, B. & S. gage, and there is one wire per slot. The entire winding is connected in series, Fig. 4. The measured resistance of the winding is 1.84 ohms at 25 degrees C.

After the sheet steel was built up in the frame, it was ground out carefully. The laminations were then removed, all burred edges taken off and the laminations again built up in the frame. The object of this was to remove all chance of eddy currents between the plates due to filing or grinding. The finished bore of the armature is 25.0625 inch.

FIELD OR INDUCTOR

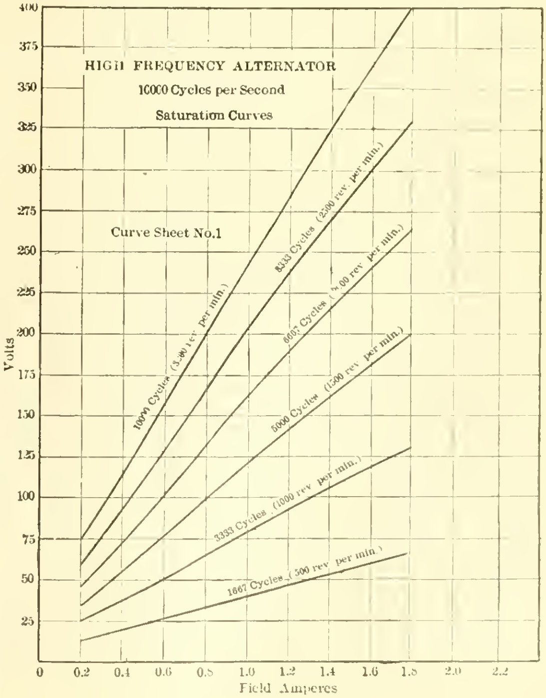
This was made of a forged-steel disc 25 in. diameter turned into the proper shape, and the poles were formed on the outside by slotting the periphery of the ring. The general construction is indicated in Figs. 1 and 5. The poles were 0.125 in. wide and about 0.75 in. long radially and were round at the pole-face. Fig. 6 shows the general dimensions of a pole.

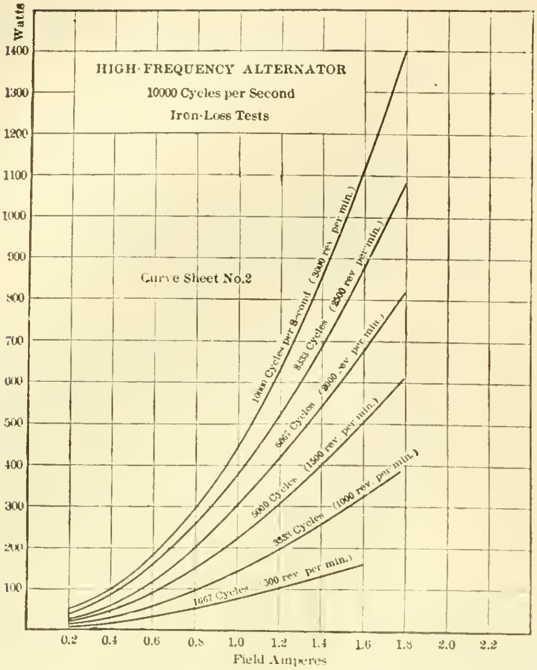
The field winding consisted of No. 21 wire, B. & S. gage. There were 600 turns total arranged in 30 layers of 20 turns per layer. The field coil after being wound was attached to a light brass supporting ring. The general arrangement of the field or inductor, armature yoke and bearings, is as indicated in Fig. 1. The measured resistance of the field winding is 53.8 ohms at 25 degrees C.

TESTS

The machine was designed primarily for only a small output, but was operated on temporary test up to 2 kw. A series of curves were taken at 500, 1000, 1500, 2000, 2500, and 3000 r.p.m., giving frequencies from 1667 to 10 000 cycles per second. At each of these speeds, saturation curves, iron losses, and short-circuit tests were made. Friction and windage were also measured at each speed. On account of the high frequency, the machine was worked at a very low induction; consequently there is an extremely wide range in pressure, the normal operating pressure being taken at approximately 150 volts.

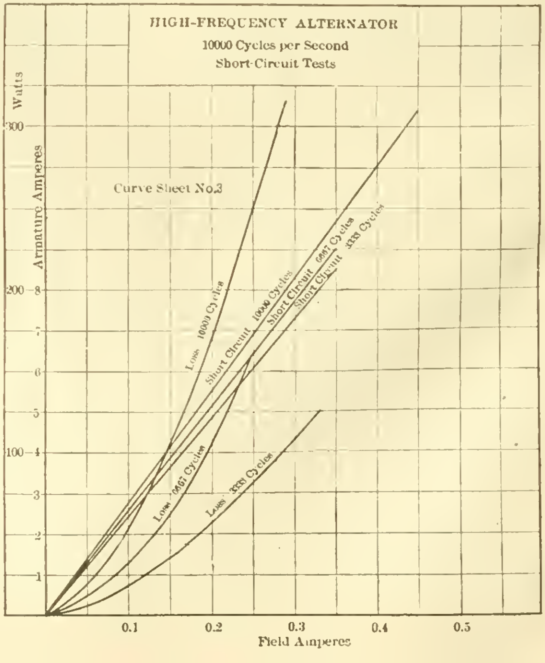
On curve sheet No. 1, the saturation curves for the various speeds are given. These curves check fairly

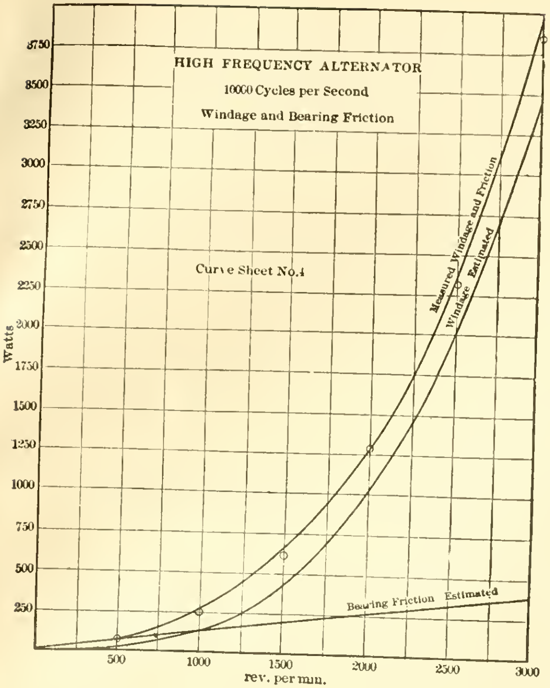




well, the pressure being practically proportional to the speed with a given field charge. This is to be expected at the lower speeds, but it was considered possible that at 3000 r.p.m. air-gap might be slightly lessened, due to the expansion of the rotor under centrifugal action; and it was also thought that eddy-current loss due to the high frequency might affect the distribution of magnetism at the armature face; but the armature iron losses were comparatively small, and there appeared to be no such effect. Also there appeared to be no effect due to expansion at high speed. The air-gap specified for this machine is 0.03125 in. on each side or 0.0625 in. total. A very small variation in the diameter of the inductor or the bore of the armature would make a relatively large percent in the effective air-gap. Therefore no reliable calculations can be made on the saturation curves of this machine based upon the specified air-gap.

Curve sheet No. 2 shows the iron losses at various speeds from 500 to 3000 r.p.m.—1667 to 10 000 cycles per second. These losses are plotted in terms of watts for a given exciting current. The curves show a rather unexpected condition as regards the losses. According to the original data showing the relative losses due to eddy-currents and hysteresis, the eddy-current loss even with these thin plates should have been much higher than the hysteresis loss, but these iron loss curves show losses with a given field charge almost proportional to the frequency, which is the ratio that the hysteresis loss alone should show. As the eddy-current loss varies as the square of the frequency, the writer expected this to be a large element in the total iron loss, especially at the higher inductions. The six curves shown on this test-sheet are fairly consistent with each other, but it should be remembered that in making measurements of such abnormal apparatus little discrepancies in the curves could easily creep in. For instance, in the saturation curve a series of experiments were first made to find whether usual types of voltmeters were satisfactory, and a number of different methods for checking these readings were used. In determining the iron losses in curve sheet No. 2, the machine was driven by a small motor and the losses measured with different field charges. Under most conditions of test the iron loss was a small element of the total loss, and therefore slight variations in the friction loss would apparently show large variations in the iron losses. Also the flywheel capacity of the rotating part of the alternator was comparatively high. Therefore, if there are any variations in the circuits supplying the driving motor, there would tend to be considerable fluctuations in the power supplied. Considering all the conditions of test, the curves appear to be remarkably consistent.





Curve sheet No. 3 shows the short-circuit curves at speeds of 1000, 2000, and 3000 rev. per min., or frequencies of 3333, 6667, and 10 000 cycles per second, respectively. It should be noted that at a given frequency the short-circuit current is proportional to the field current over the entire range measured but that the short-circuit current is not the same for the same field current at the various frequencies. According to these curves the current on short circuit increases somewhat with the given field charge as the frequency is increased.

Curve sheet No. 4 shows the measured windage and friction losses plotted at speeds from 500 to 3000 rev. per min. This curve indicates clearly that the windage is the principal friction loss at the higher speeds. The writer has added two curves, one showing the estimated bearing friction loss, and the other the estimated windage, based upon the assumption that the bearing friction varies directly as the revolutions and the windage loss with the third power of the revolutions. The small circles lying close to the measured loss curve show the sum of these estimated losses, and the agreement with the measured loss is fairly close over the entire range.

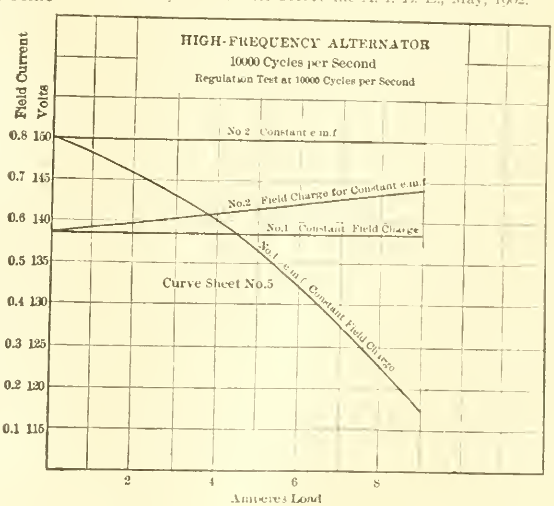
Curve sheet No. 5 shows regulation tests made at 150 volts. The power-factor of the load on this test was not determined, as it was extremely difficult to make accurate measurements. The load consisted of incandescent lamps and the wiring from the machine to the lamps was non-inductive for the usual frequencies; but at the abnormal frequency of 10 000 cycles per second it is more difficult to obtain a true non-inductive load with ordinary apparatus. The tested regulation indicates that the load was practically non-inductive.

In first undertaking tests on this machine there was considerable difficulty in measuring the pressures. It was found that at a frequency of 10 000 cycles per second the Weston voltmeter did not work satisfactorily. Practically the same deflection was obtained on the high and low scales of a 60-120 volt Weston alternating-current direct-current voltmeter with the same pressure.

Very good results were obtained by the use of a form of static voltmeter devised by Mr. Miles Walker*. Tests were also made with the Cardew hot-wire voltmeter with the high frequencies, and the results checked very satisfactorily with the static voltmeter.

For measuring the current a current dynamometer was used which had wood upright supports and a celluloid dial. The only metal parts outside of the copper coils were brass screws. It was found that the current dynamometer is not affected by frequency, unless there are adjacent metal parts in which eddy currents can be generated which react upon the moving element. The dynamometer used had but a few turns in order to reduce the pressure drop across it. This dynamometer was checked very carefully at different frequencies and

*This voltmeter is of the same form as the static wattmeter described by Mr. Walker before the A. I. E. E., May, 1902.



apparently gave similar results for any frequency between 25 and 10 000 cycles.

Several temperature tests were made on this machine. The heaviest load on any test was 13.3 amperes at 150 volts, or 2-kw output. This test was of two hours' duration, and at the end the armature iron showed a rise of 16 degrees C.; the armature copper 21 degrees C. by resistance, and the field copper 17.3 degrees C. Air temperature 19 degrees C. The machine showed a relatively small increase in temperature at this load over the temperature rise with one-third this load. This was probably due to the fact that the windage loss was so much higher than the other losses of the machine that the temperature was but little affected by the small additional loss with increase in load.

Attempts were made to utilize the current from this machine for various experiments, but difficulty was at once found in transforming it. At this high frequency no suitable iron-cored transformer was available. Transformers with open magnetic circuits were tried and operated better than those with iron cores but were still rather unsatisfactory. It was decided that nothing could be done in this line without building special transformers.

Among the few experiments made was that of forming an arc with current at this high frequency. This arc appeared to be like an ordinary arc so far as the light was concerned, but had a very high-pitched note corresponding to the high frequency. This note was very distressing to the ears. This machine is in reality of the nature of a piece of laboratory apparatus; and at present (1904) it has no commercial value. It was designed primarily for scientific investigation, and appears to be a very good machine for that purpose.

Continuous Wave Radio Receivers

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Radio Engineer,
Westinghouse Electric & Mfg. Company

The extensive use of continuous waves, or waves having a constant amplitude, is only possible through the use of the heterodyne method of reception, invented by Prof. R. A. Fessenden. The greatly increased selectivity of the receivers and freedom from interference, due to the character of the radiated waves from the continuous wave transmitters, makes it possible to operate more stations in the same locality, than it is possible to operate using spark or other damped wave transmitters. A brief outline of some methods which have been used and are used at the present time, for increasing the selectivity of the receiving circuits, detecting or rectifying the signals and for amplying the received energy is given in the following article.

IT IS no longer possible to make a simple list of the most practical or useful antenna, tuning circuits or detecting and amplifying equipment for receiving radio signals. The most useful equipment must be determined by the class of service for which the equipment is intended. Some of the principle factors which determine the type of apparatus to be installed are:—

1—Strength of signals.
2—Type of signals to be received. Spark, modulated continuous waves, telephone or continuous waves.
3—Character of possible interference.
4—Atmospheric disturbances.
5—Wave lengths to be received.
6—Reliability of service desired.

The forms of the conductors used for receiving radio signals vary greatly, and depend upon the conditions at the place of installation. The two forms most used are the open antenna and the coil or loop antenna. Underground wires consisting of insulated wires buried in the earth with the receiving instruments connected between the wires and ground, or between two such wires, have been used to a certain extent. Underground wires are sometimes placed in iron pipes, from which they are insulated, and the pipes buried in the ground.

In computing the e.m.f. induced in either open or coil antennae, the same result is obtained whether the electromagnetic or electrostatic component of the field is considered. The e.m.f. induced in an open flat-top antenna is proportional to its height. The antenna is usually tuned to the same frequency as the induced e.m.f., that is, the capacity reactance $\frac{1}{\omega C}$, of the antenna, is balanced by inserting an inductance of the proper value to produce an inductive reactance ωL, so that the impedance is simply the resistance of the antenna, and the current that flows is $I = E \div R$.

In the resistance of the antenna is included all the losses which give rise to counter-e.m.f.'s which oppose the flow of current in phase with the driving e.m.f.; the resistance is due to the ohmic resistance of the wire and ground system, the dielectric losses and the radiated energy. The radiation resistance of an antenna increases with the height. It is evident, therefore, that if the resistance of the antenna wires and ground systems could be sufficiently reduced, the current would be independent of the height of the antenna.

For receiving, the use of a low antenna with a low effective height, may be of great advantage if the losses due to the resistance of the antenna wire and ground system are small. For a given field strength, a long wave length is also advantageous for receiving, since the radiation resistance decreases as the square of the wave length for a given antenna.

An e.m.f. is induced in a coil antenna by a passing electromagnetic wave because of the time variation of the magnetic flux through it. The e.m.f.'s induced in the two vertical sides of the coil, if the plane of the coil is parallel to the direction of propagation of the wave,

are not in phase, due to the time required for the wave to travel from one side of the coil to the other, therefore, there is a resulting e.m.f. acting to send current through the coil. If the plane of the coil is perpendicular to the direction of propagation of the waves, the e.m.f.'s are in phase and opposed, so that there is

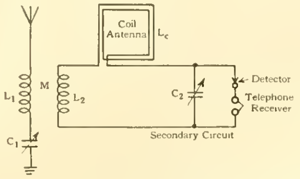

FIG. 1—COMBINATION OF A COIL ANTENNA AND OPEN ANTENNA AS A RECEIVING SYSTEM

For eliminating interference and determining the direction of a transmitting station.

no resulting e.m.f. The e.m.f. acting to send current around the coil is proportional to $a^2\ n\ l$, where a equals the length of side of a square coil, n equals the number of turns in the coil, l equals the wave length. The voltage reception factor, which is useful in operating a detector is a^2nL/R, where L equals the inductance of the coil, and R equals the resistance of coil. Small coils which have several turns are usually used for receiving. The most efficient coils for the wave length to be received are most conveniently determined experimentally, because the resistance cannot be calculated.

A coil aerial is not as efficient for receiving over a wide range of wave lengths, as an open antenna, due chiefly to the fact that the e.m.f. induced in the coil varies inversely as the wave length, while it does not vary with the wave length in the case of an open antenna. The directional properties of coil antennae are utilized for reducing interference, by rotating the coil so that a zero is obtained on the wave from the interfering station, while the desired signals can be received, provided the two stations and the coil are not in line.

Coil antennae are used for finding the direction of transmitting stations and, when one is used in combination with an open antenna, it is possible to determine the direction of the transmitting station. The combination of a coil and open antenna as a receiving system, when connected as shown in Fig. 1, may be employed for eliminating the interference caused by a nearby transmitting station, or for determining the absolute direction of a transmitting station.

The elimination of the interfering signals is accomplished as follows. The coil antenna is tuned to the desired signal, that is, the values of inductance and capacitance are adjusted to neutralize each other at the desired frequency. The open antenna is employed to receive the undesired signals and by adjusting the coupling between L_1 and L_2 the interfering signals received on the coil antenna may be balanced-out by the signals received on the open antenna. A shift in phase of 180 degrees between the interfering signal received in the coil antenna and that received in the open antenna may be accomplished by turning the coil antenna 180 degrees and smaller variations in phase between the same signals, received on the coil and the open antenna, are secured by detuning the open antenna, causing the current either to lead or lag the induced voltage. The amplitude of the signals received on the open antenna must be sufficient to balance the signals received on the coil antenna, even when the open antenna is slightly detuned.

If the combination coil and open antenna have been previously calibrated by locating a station whose direction is known, it is possible to determine the absolute direction of other stations by rotating the coil to the position of maximum or minimum signal strength.

Coil antennae have proved useful in eliminating static interference, especially on the shorter wave lengths and when the conditions are such that a high open antenna becomes charged to high potentials.

METHODS OF TUNING

The main object of tuning the circuits of a radio receiver is to reduce the impedance of the circuits to a minimum value for the signals to be received and to produce a high impedance for all other frequencies. As will be pointed out in the following paragraphs, the above objects are much easier to obtain with continuous waves than with damped waves. Radio receivers must provide a means for loading the antenna, by inserting inductance so as to cover a large range of wave lengths. The best arrangement is one in which a large inductance in series with a variable air condenser is placed in the antenna circuit. This arrangement permits a high value of L/C which insures a sharper resonance curve, or in other words a higher ratio of the impedance offered at other frequencies to the impedance at the resonance frequency. Such a circuit is resonant to only one frequency, while circuits employing condensers in parallel to the inductance may be resonant to several frequencies.

The use of loosely coupled secondary circuits tuned to the same frequency as the antenna circuit, Fig. 2, is a great advantage, especially when continuous waves are used. For continuous waves the only current ex-

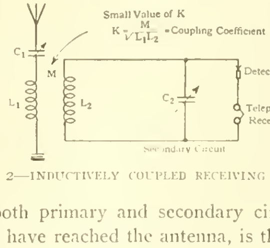

FIG. 2—INDUCTIVELY COUPLED RECEIVING CIRCUIT

isting in both primary and secondary circuits, after a few cycles have reached the antenna, is the forced continuous current resulting from the continuous received voltage. The resonance curve of a receiver with a tuned secondary circuit for continuous waves is found by taking the product of the ordinates of the resonance

curves of the antenna circuit and secondary circuit. The sharpness of tuning or selecting is, therefore, greatly increased by the use of a loose coupled, tuned secondary circuit, as compared to the selectivity obtained with a single tuned circuit. In the resonance curve referred to, the ordinates represent the received

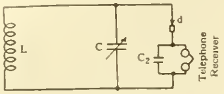

FIG. 3—SECONDARY CIRCUIT OF RECEIVING SYSTEM

current and the abscissae the frequency of the impressed voltage.

The waves radiating from a spark transmitter consist of a number of damped wave trains. The initial amplitude of each wave train from a spark transmitter is the greatest and the current falls to zero after a relatively few cycles. The spark signal consists of a number of these short waves trains, and there is a transient current at every spark discharge of the transmitter. Therefore, there are usually two currents induced in the receiving antenna, one of the impressed frequency and decrement and the other the natural frequency and decrement of the receiving antenna. Since the secondary circuit is tuned to the same frequency as the antenna circuit, the natural oscillations of the antenna will induce a current in the secondary, even if the impressed voltage produces no appreciable current in the secondary circuit.

Coupled circuits have been found to improve the selectivity of receivers for spark reception materially. However, the coupling cannot be made as loose as for continuous waves, without a loss of signal strength. Extremely loose coupling increases the sharpness of tuning without materially sacrificing signal strength, if the signals are not too highly damped and if the resistance of the secondary circuit is not too high.

DETECTORS

The currents induced in radio receivers are usually of small amplitude, hence only very sensitive apparatus can be used for their detection. Various devices have been used for detection, such as the coherer, "barreter" and thermal detectors. Several forms of magnetic de-

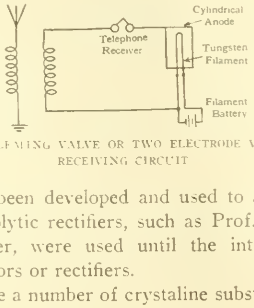

FIG. 4—THE FLEMING VALVE OR TWO ELECTRODE VACUUM TUBE RECEIVING CIRCUIT

tectors have been developed and used to a certain extent. Electrolytic rectifiers, such as Prof. Fessenden's liquid barreter, were used until the introduction of crystal detectors or rectifiers.

There are a number of crystaline substances which, when in contact with a metal or another crystal, have a much higher resistance for an e.m.f. in one direction across the contact than for the same value of the e.m.f. in the reversed direction and, therefore, conduct unilaterly. It is evident that a rectifier connected in a circuit as shown in Fig. 3, at *d*, will cause a charge to accumulate on the condenser C_2 when an alternating current is flowing in the circuit *LC*. If the alternating current is of radio frequency and is interrupted at an audible rate, or modulated by the voice as in radio telephony, the simple rectifier will cause the charge on C_2 to vary with the amplitude of the radio frequency current. Current flows through the telephones, as a result of the voltage on C_2 and is proportional to this voltage. Several forms of crystal detectors are in use at the present time for damped wave reception, some of which are very sensitive.

The Fleming valve, a two electrode vacuum tube containing a negative electrode, consisting of a heated filament, and a positive electrode of cylindrical form

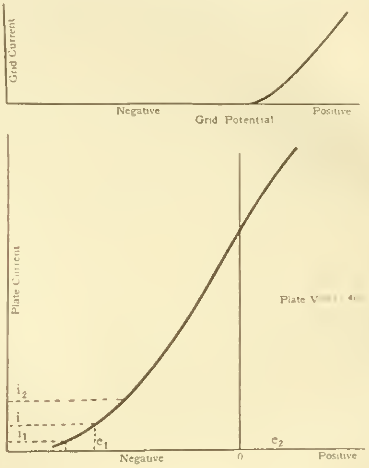

FIG. 5—CHARACTERISTIC CURVES OF A THREE ELECTRODE VACUUM TUBE

arranged in a circuit, as shown in Fig. 4, was used by the Marconi Company as a detector. While probably no more efficient than some crystals the Fleming valve is stable and does not require frequent adjustment. The current flows through the Fleming valve from the cylindrical electrode to the heated filament. However, the flow is possible only through the movement of negatively charged electrons, emitted by the hot filament, to the cylindrical electrode. A two electrode valve is therefore, a perfect rectifier when highly evacuated.

The three electrode vacuum tube, invented by Dr. De Forest, has replaced all other types of detectors, except in places where the installation is not of sufficient importance to warrant the extra cost of the batteries required for heating the filament, and of the necessary apparatus for charging the batteries.

In order to bring out the relative merits of the various schemes for operating the three electrode tube

as a detector, it is necessary to refer to a characteristic curve of plate current vs. grid potential and grid current vs. grid potential, Fig. 5. To function as a detector, the three electrode tube must be the equivalent of a rectifier, or must be able to translate a train of radio frequency waves into a single variation of current in the indicating device, which is usually a telephone receiver. A three electrode tube connected to a circuit in which radio frequency oscillations exist, as shown in Fig. 6, will act as a detector, if the alternating voltage

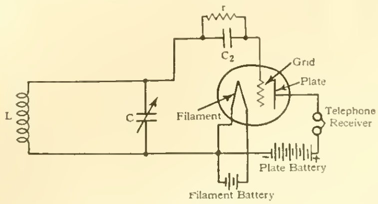

FIG. 6—CONNECTIONS FOR USING THE THREE ELECTRODE VACUUM TUBE AS A SIMPLE DETECTOR

acting on the grid causes a larger increase in the plate current on one-half cycle than the corresponding decrease on the other half cycle. This would be the case if a steady negative grid voltage e_1 were impressed on the grid in Fig. 5 and the alternating-current voltage V_1 impressed on the grid caused a current variation between the limits i_1 and i_2. Since the steady plate current would be i, it is evident that a net increase in the plate current will result, due to the impressed alternating-current voltage.

A more efficient method of employing the tube as a detector is to make use of its amplifying properties. Since a certain change in voltage applied to the grid will cause a greater change in the plate current than would result for the same change in voltage on the plate, the tube will function virtually as a voltage amplifier. The ratio of the change in plate voltage necessary to cause the same change in plate current, as is produced by a given change in grid voltage, is called the voltage amplification factor of the tube. If a tube is connected as shown in Fig. 7 to a circuit in which radio frequency current is flowing, and the steady potential on the grid is fixed at a value e_2, Fig. 5 (more positive than the negative end of the filament, for high vacuum tubes) the condenser C_2 will be charged by the rectified current resulting from the unilateral characteristic of the grid current, grid voltage curve. The charge on the condenser will be such that the grid potential is made more negative with respect to the filament and the plate current is decreased. The plate current returns to the normal value when the charge on C_2 leaks off through r. In this case there is both rectification and amplification.

A much greater amplification of the received signals can be obtained by use of the regenerative circuits, invented by Mr. E. H. Armstrong. The simplest form of the regenerative circuit is shown in Fig. 8. In this arrangement the plate circuit is coupled to the grid circuit by the mutual inductance between L_1 and L_2. The radio frequency voltage impressed on the grid causes a radio frequency current, as well as the audio frequency current, to flow in the plate circuit. A condenser C_4 is used to by-pass the radio frequency current around the telephone receivers. The inductance L_1 is too small to be taken into account for audio frequencies. The radio frequency current in the grid circuit, reinforced by the plate current due to the mutual inductance M_1 and condenser C_2, accumulates a final charge proportional to the final amplitude of the current in the grid circuit. The mutual inductance M_1 may be sufficient to feed back enough energy to the grid circuit to cause the current to continue to oscillate in the circuit L_2C_1. For short wave lengths C_1 may be omitted and the circuit tuned by means of a variable inductance with the capacity of the coils and tube alone.

Another form of regenerative circuit, which is suited for receiving circuits for short waves is shown in Fig. 9. The variable inductance L_3 is placed in the plate circuit. The voltage produced across the inductance L_3 causes a current to flow through the capacity between the elements of the tube, (shown dotted) which produces a voltage on the grid to reinforce the original voltage. The smaller the value of C, the more pronounced is the effect.

The regenerative vacuum tube circuits are the simplest and most efficient means at the present time for the reception of damped wave signals if extreme amplification is unnecessary. Tubes containing a considerable amount of gas are more sensitive detectors than tubes having a high vacuum. The presence of gas causes the tube to have a lower impedance due to the positive ions formed, which tend to neutralize the space charge of the electrons. For a definite plate voltage, the plate current in a high vacuum tube is usually limited by the neutralizing effect of the negative charges of the electrons on the field from the positive plate, in the space near the filament. Therefore increasing the filament temperature and the number of electrons

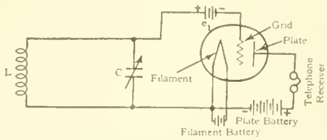

FIG. 7—CONNECTIONS FOR USING THE THREE ELECTRODE VACUUM TUBE FOR SIMULTANEOUS AMPLIFYING AND RECTIFYING

emitted from the filament, will not cause more electrons to be drawn from the filament to the plate. If there is gas in the tube, positive ions are formed between the grid and plate and these combine with electrons to reduce the space charge, thus permitting a greater flow of electrons to the plate. The grid which is placed between the filament and the plate regulates the passage of the electrons through it. If the grid is negative, the passage of the electrons through it is retarded, and also some of the positive ions are drawn to the grid, which

may result in the neutralization of the space charge to a lesser degree and, therefore, a reduction in the flow of electrons to the plate, due to both effects. The presence of positive ions may also result in a grid-current, grid-voltage characteristic which is more efficient for rectification than can be obtained in the high vacuum tubes. The unilateral conductivity between grid and filament is greater when positive ions are present in the right amount.

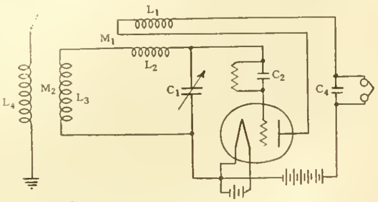

FIG. 8—ARMSTRONG REGENERATIVE CIRCUIT
For simultaneous amplifying and rectifying

Gaseous or soft tubes, while they are remarkably sensitive as detectors, require a source of variable plate voltage and filament current. The adjustments usually have to be made frequently on account of the heating of the gas by the hot filament, etc. It has not been possible to make gaseous tubes containing a uniform amount of gas, therefore, such tubes have to be carefully selected or many of them may be worthless. It is doubtful if soft tubes are to be recommended for practical use in any case, because of the necessary adjustments. The hard tube is a less sensitive detector which requires no attention, gives uniform results at all times, and is interchangeable with similar tubes without making adjustments, and is to be preferred.

In addition to the amplification resulting from the use of regenerative vacuum tube circuits, a great increase in selectivity is obtained, due to the reduced damping of the wave length to which the circuit is tuned. The advantages of using continuous waves for radio communication from the standpoint of receiving circuits has been pointed out. Most of the older methods of detecting continuous waves, however, are unsuited for practical work. Some of the devices which have been used are the tikker, tone wheel and several schemes for causing the incoming signal to control a local source of audio frequency current through the telephones. All of these schemes require apparatus in addition to the detector. For example the tikker and tone wheel require driving motors, while the last mentioned scheme requires a source of local audio frequency current. If continuous wave telegraphy, with all its advantages over other systems, is to become popular, a simple and efficient detector is necessary and this is available in the form of the oscillating vacuum tube. The maintenance cost is no more than for a simple regenerative spark receiver or any vacuum tube detector. As to the apparatus required and the operation, it is practically the same as for efficient spark reception.

While the use of the vacuum tube as a beat or self-heterodyne detector is due to Major Armstrong, the method of beat reception of continuous waves was invented by Prof. Fessenden before the invention of the vacuum tube. Prof. Fessenden combined with the inaudible frequency current being received, a current from a local generator, having a frequency differing from the signal current frequency by the number of cycles required to give the desired audio frequency note. The combined currents were passed through a telephone receiver which produced distortion, or one which had no permanent magnet. The practical type first used had a core of iron wires in the winding through which the current passed and instead of an iron diaphragm a mica diaphragm carrying a coil of fine wire was used.

It is evident that, if the combined currents are rectified by any method and the current passed through a telephone receiver, an audio frequency note of the same frequency as the beats will be heard. The three electrode vacuum tube may be used to generate the local radio frequency current which beats with the received signals and to detect the beat note at the same time, and when functioning as a generator and heterodyne detector it amplifies the signals as well, due to the coupling between the plate and grid circuits. Armstrong found that the amplification secured with the self-heterodyne as compared with a simple chopper circuit was about 5000 times*. The efficiency of a self-heterodyne vacuum tube depends upon the amplitude of the local oscillations, which is easily controlled by means of a variable coupling between the plate and grid circuits. The secondary circuit of the receiver is usually the circuit which determines the frequency of the local current and in order to obtain a frequency to give a beat note suitable for aural reception of long wave lengths, the secondary must be detuned appreciably. For long wave lengths, such as are used for transoceanic communication, it is advisable to use only sufficient coupling between the grid and plate circuits to obtain amplication and to use separate heterodyne generators for supplying the local current. The tuned circuit to which the detector is connected can then be tuned exactly to the incoming signals.

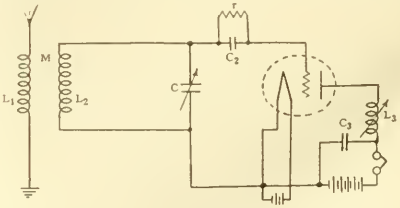

FIG. 9—REGENERATIVE CIRCUIT SUITED FOR RECEIVING SHORT WAVES

The vacuum tube, used as a detector of damped or modulated waves, as well as all rectifying detectors, gives a signal in the telephone which is proportional to the square of the voltage impressed on the grid. But

*E. H. Armstrong, Proc. I. R. E. 1917.

when the vacuum tube is used as a self-heterodyne detector or when a separate heterodyne generator is used with any detector, the response is proportional to the first power of the impressed signal voltage. This characteristic renders this method of detection equally efficient for weak or strong signals.

AMPLIFIERS

There have been many attempts made to develop suitable apparatus for amplifying weak alternating currents, or in other words to control considerable power by a weak current. For telephone signals, it is necessary to have the controlled current follow exactly the variations of the controlling current. The "Brown Relay" and the "Schreeve Repeater" have been fairly successful and such devices still have their application. The three electrode vacuum tube, however, is rapidly replacing all other devices as an amplifier of alternating current and, in some instances, it is being used to replace ordinary relays in direct-current telegraph lines. Amplifiers may be used to increase the sensitiveness of a receiving set either by amplifying the radio frequency signal current before it is rectified or by amplifying the audio frequency current resulting from the rectification.

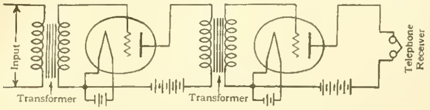

FIG. 10—CONNECTIONS FOR CASCADE AMPLIFICATION

The tubes are usually connected in cascade and the plate and grid circuits connected through a transformer, as shown in Fig. 10.

In radio receiving sets it is not practical to use more than two efficient stages of audio frequency amplification when receiving by ear, due to the fact that some nearby spark transmitter may start up on the wave length to which the receiver is tuned and cause considerable discomfort to the operator. Static and other disturbances are also amplified to such an extent, when extreme audio frequency amplification is used, that the ear is quickly fatigued and weak signals cannot be read as easily as if both the noise and signal were weaker.

In continuous wave systems with heterodyne reception it becomes possible to use amplifiers that amplify only one frequency and, therefore, very great selectivity is obtained and the ratio of the noise due to static induction and noises inherent in the amplifier itself are greatly reduced in comparison to the signal obtained.

For the operation of loud speaking telephone receivers, which require considerable power for proper operation, several tubes may be connected in parallel. Tubes capable of handling several watts in the plate circuit are desirable in connection with instruments for use in large halls and in the open air.

Radio frequency amplification may be used to advantage in case the signals are weak and the amplification obtained with two stages of audio frequency is not sufficient. Since a vacuum tube detector, and in fact most detectors of damped waves, gives an audio frequency signal approximately proportional to the square of the impressed voltage for weak signals, it is obvious that the efficiency of the receiving system is greater if the amplification is accomplished at radio frequency. The detector acts as a limiting device to limit the strength of the audio frequency signal, so that signals cannot increase too much, but weak signals are brought nearer to the same strength as the strong ones in telephones. By using three or four stages of radio frequency amplification with a detector in connection with the coil antenna, it is possible to use a very small coil antenna, which can be rotated for the purpose of eliminating interference or for direction finding, and to obtain signals of strength equal to those received on a large open antenna with a detector and two stages of audio frequency amplification.

A great advantage of radio frequency amplification is that the number of stages or amount of amplification is not limited by noises inherent in the amplifier and by low frequency induction noises picked up by the receiving set, due to the fact that the amplifier is capable of amplifying only high frequencies.

Tubes having a high vacuum or hard tubes are required for use with multi-stage amplifiers, as the characteristics of the tubes must be known and be uniform, and it is practically impossible to keep six or seven soft tubes in adjustment long enough to receive a message.

It is desirable to have the internal plate circuit impedance of amplifier tubes low and the grid to filament impedance high, on account of the apparatus which must be associated with the tubes. The transformers for connecting the tubes in cascade can be made more efficient the lower the plate circuit impedance, and the voltage can be stepped up more in the transformer with higher grid to filament impedance. In general low plate circuit impedance results in a low voltage amplification factor but it is difficult to utilize the full voltage amplification of tubes having an impedance higher than approximately 40 000 ohms in the plate circuit, as efficiently as for tubes having a lower plate circuit impedance.

Radio Arc Transmitters

Q. A. BRACKETT

FOR NEARLY 20 years radio communication has been centered around the original system of Marconi, wherein the discharge of a highly charged condenser across a spark gap was utilized to set up high frequency oscillations in a radiating circuit. Improved as it was by many eminent engineers as the years went by, it remained always a system emitting trains of waves that were more or less highly damped instead of continuous. Engineers soon came to realize how much superior the effectiveness of undamped or continuous waves would be if only a satisfactory source were available. The search for such a source developed ultimately along three lines, viz. the arc, the high frequency alternator and the vacuum tube. The latter came into the field only in recent years and can hardly as yet be considered commercialized. The high-frequency alternator has taken from ten to fifteen years to perfect and even now is considered suited only to extra high power stations operating on a fixed wave length. The great burden of continuous wave radio communication has, therefore, fallen upon the arc, because of its feasibility in moderate sizes and the readiness with which it can be adjusted to operate at various wave lengths.

The fact than an electric arc functions like a negative resistance i.e., that its voltage drop decreases with increase of arc current, has been known since the earliest days of the illuminating arc lamp. It remained, however, for Elihu Thomson, in 1892, to discover the fact that, under certain conditions, the arc could be made to oscillate even though supplied with direct current. From this Duddell in England, about 1900, developed the so-called "singing" or "talking" arc which was a favorite laboratory curiosity of a decade ago. It was learned that if a direct-current arc, supplied from a source of constant-current characteristic, was shunted by a capacity, or a capacity and inductance in series, an alternating current would flow in the shunt circuit. This was due to the alternate charging and discharging of the condenser as the arc voltage rose and fell, due to the negative characteristic of the arc as the condenser alternately robbed it of current and then returned it superimposed upon the normal arc current. The frequency of these alternations was determined by the constants of the shunt circuit and was comparatively low, giving rise to the term "singing arc" as the current fluctuations in the arc flame gave rise to an audible sound of the same pitch.

FIG. 1 500 KW ARC CONVERTER
With closed magnetic circuit.

When the circuit was properly adjusted the arc remained in a very sensitive state, wherein any disturbance in the circuit would be reproduced audibly by the arc flame. In this way, the arc could be made to reproduce music or speech directed into a microphone associated with the arc circuit in any one of various ways. As stated above, this was a very interesting laboratory experiment, but had little practical utility

except as a novelty for advertising purposes. It was for instance, utilized in New York in 1907 in connection with the ill-fated "Cahill Telharmonium" method of electrically-creating and distributing music. In the concert hall at 39th Street and Broadway, after the regular concert program using a form of telephone receiver and horn as a reproducer, the final numbers were heard coming from the flame of an arc lamp overhead. The effect was indescribably weird and mysterious to the average listener. It was when hearing a description of such a talking arc that Mark Twain is alleged to have said that he could see in his mind's eye the King of England driving up the street while all the arc lamps along the route played "God save the King."

Although many engineers and physicists experimented with the oscillating arc, only oscillations of low

FIG. 2—30 KW ARC CONVERTER
With open magnetic circuit.

frequency and feeble intensity were obtained. It remained for Valdemar Poulsen of Denmark to make the next big step in development which took the oscillating arc out of the class of laboratory curiosities and placed it firmly among valuable utilities.

In 1902, Poulsen announced his discovery of the possibility of producing oscillations of high frequency from an arc in an atmosphere of hydrogen. The use of a strong transverse magnetic field across the arc and the artificial cooling of the anode were other important refinements of his design. For years, however, the arc was unable to win its way in competition with the already established spark system. There were various reasons for this. In the first place, the demand at that time was for comparatively small radio sets operating at short wave lengths. In this field the arc is not at its best, as it is unstable at short wave lengths and in small sizes. Thus its most serious difficulties were encountered first. It took time to develop the arc to the large powers now common and to create the demand for them.

The main reason, however, why the arc was slow in coming into use was that the signals were entirely inaudible with the existing types of receiving apparatus, unless interrupters were used to break up the wave trains into audible frequencies. It was almost impossible to construct an interrupter that would handle satisfactorily the power at the transmitter so that any receiving set could listen, although so called "choppers" were developed and used with small sets or at reduced power. Prof. Pedersen, Poulsen's co-worker at Copenhagen, developed an interrupter method of receiving, called a "tikker", that was the most satisfactory method in use for many years, but in comparison with modern methods it was quite inefficient.

About this time, Prof. Fessenden invented what he called the "heterodyne method" of reception, which was destined to prove the ultimate solution of the problem and make practicable the use of the arc and other methods of undamped or continuous wave transmission. This consisted in generating locally at the receiving station a feeble oscillating current of an adjustable frequency close to that to be received, and superimposing the two frequencies, thus causing interference beats between them, when rectified, of any desired audio frequency. This method, however, could not be used for lack of a cheap and convenient source of local oscillations. Fessenden in his experiments used one of the only two high frequency alternators built at that time.

It was, therefore, not until 1912 when Armstrong, in this country, discovered the method of generating high-frequency currents by causing a De Forest audion to oscillate through interlinking its plate and grid circuits, that the heterodyne method became available for practical use. Now it is an indispensable part of all modern commercial receiving sets.

At the time when the oscillating audion was developed for reception, the oscillating arc had been perfected and built in large sizes until today most of the large stations of the world are equipped with the arc transmitter. Likewise some of the larger ocean liners and United States Naval craft employ arc sets of moderate size to ensure long distance communication such as could not be obtained from the spark sets.

The modern arc transmitter consists fundamentally of a direct-current arc, operated in an atmosphere of hydrogen in a strong transverse magnetic field, and shunted by an oscillatory circuit containing inductance and capacity. While the latter may form a local circuit inductively coupled to the radiating circuit, it is at present more common to use the arc directly in the antenna. In such cases the shunt oscillatory circuit consists of the capacity of the antenna and its inductance, increased by such additional loading coils inserted in series with the antenna as may be necessary to obtain the desired wave length. The latter is determined by the constants of the shunt oscillating circuit.

The transverse magnetic field may be shunt or separately excited, but is more usually obtained from coils in series with the direct-current supply to the arc, which also may serve as protective choke coils to hold back the radio frequencies from the direct-current generator and as energy-storing choke coils to maintain the supply current constant, so that the arc will oscillate. Whether the iron magnetic circuit is open or closed is not vital, provided there is sufficient field strength across the arc, and depends, therefore, upon practical questions of design such as size, weight, cost and ease of installation. Most of the small arc converters of American design have open magnetic circuits, while most European arcs and all large converters have closed magnetic circuits. For use on small steel ships, the closed circuit design is to be preferred, as it reduces the disturbance of the ship's compass caused by stray flux in the case of the open circuit type.

The hydrogen atmosphere is usually obtained most conveniently through the decomposition of some hydrocarbon, such as alcohol, by enclosing the arc in a chamber of some non-magnetic material and allowing the hydrocarbon to drip into the arc at a suitable rate which can be adjusted as desired.

In order, however, that the arc may be made to oscillate in a stable manner when handling considerable power, it is necessary to keep the anode cool, and for this reason it is customary to make the latter of hollow copper and cool it by a continual flow of water through it. On the larger arcs, the arc chamber and the anode and cathode holders are likewise water cooled, a small centrifugal pump being used to circulate the water from a storage tank. In this way much higher arc voltage can be used and more power can be developed.

The cathode is usually a round carbon rod which is rotated slowly by a motor through worm gears, so as to make the burning uniform. As the oxygen in the enclosed arc chamber is rapidly consumed the carbon does not necessarily burn away as in ordinary arcs, but may actually grow longer, due to deposition of carbon from the hydrocarbon atmosphere. Usually the end of the cathode develops a shape like the head of a mushroom.

Ordinarily the cathode is grounded directly through the arc chamber and the frame of the arc converter. It, therefore, needs little clearance from the pole faces. The anode, however, is usually flattened so as to increase its separation from the poles to a safe amount for the voltage involved.

Fig. 4 shows a typical diagram of connections of an arc transmitter direct connected to an antenna. The direct-current generator, driven by any convenient means, delivers current through the magnet field coils *FF* and the radio frequency choke coil *RF* to the water cooled anode *A* and the slowly rotated carbon cathode *C*. The anode *A* is connected to the antenna through the loading coil *L*. The choke coil *RF* may be dispensed with if the end turns of the main field coils are insulated so that they are able to stand the impact of the radio frequency generated by the arc. The field coils and magnet systems are so proportioned as to give the necessary field strength at the arc which is of the order of 20 kilogausses.

The antenna capacity and the loading coil *L* in effect constitute a shunt circuit around the arc and cause continuous alternating currents to be generated by the arc of a frequency determined by the capacity and inductance. Changes of wave length are easily made by changing taps on the loading coil. If a wide range of wave lengths is desired, it may also be necessary to change taps on the magnet field coils at the same time, as not all wave lengths require the same field strength.

It is, of course, impossible to signal with an arc converter by causing the telegraph key to interrupt the power supply, as in the case of spark sets, because it would be necessary to bring the electrodes together and

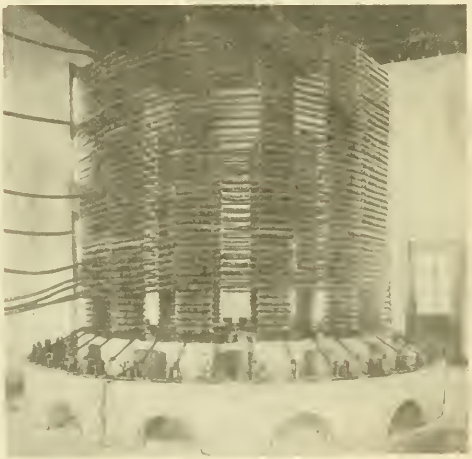

FIG. 3—ANTENNA LOADING INDUCTOR AND SIGNALING SYSTEM

Of a high power radio station equipped with arc transmitter.

restart the arc after each interruption. It is true that something like this has been done successfully in the case of the smaller sets, where the arc is restarted, without moving the electrodes, by means of a high-voltage pilot spark. On all medium and large size arc sets, however, it has been found necessary to avoid interrupting the arc.

The simplest scheme and the one most generally in use up to the present time is called the "compensated wave" method. This consists of signaling by changing the emitted wave length slightly, so that when the key is up the signals are inaudible or of noticeably changed pitch in the receiver. This is usually accomplished by short-circuiting a few turns of the antenna loading coil or of a coil inductively coupled to it. The beauty of this scheme, from an operating standpoint, is that it is only necessary to short-circuit a very small percentage

of the total inductance to cause sufficient change of wave length to give good signals. This means that the relay key contacts have to handle only a very small part of the total energy; which makes the problem of design much easier. For instance, if the incoming wave is of 100 000 cycles and a heterodyne receiver is used to generate locally 100 500 cycles, the signals are received as an audible 500 cycle note. It is only necessary, therefore for the sender to change the transmitted frequency 500 cycles or one-half of one percent between signals to make the received frequency equal to the locally generated frequency, so that nothing would be heard in the receivers, between the dots and dashes. Under these conditions, therefore, the signals received would vary from 500 cycles to complete inaudibility when the sending key was used to short-circuit only about one percent of the loading inductance.

This compensated wave method of signaling is used on the great majority of arc sets above two kilowatts and on practically all above 50 kw. However, while it provides a very attractive method of signaling from an operating standpoint it has one serious drawback, and this is sufficient practically to assure the abandonment of this method of sending. This is due to the fact that it uses up two wave lengths for one station. Not only does the station radiate two wave lengths, but it also sends out energy at those instants when normally it should be silent, that is, between the dot and dashes of the telegraphic signals. To make it still worse, it also radiates during the intervals between messages, that is, while the operator is receiving, unless the arc is stopped entirely, which is often not convenient.

For this reason active development has been carried on to perfect a method of signaling that would prevent the arc from radiating energy except during the dot and dash signals, and then at only one wave length. The success of this development has made it almost certain, that in the near future radio regulations will forbid the use of the "compensated wave" method of sending.

The best of the schemes developed is the "uniwave key", invented by Lt. W. A. Eaton* of the U. S. Navy and manufactured by the Westinghouse Company. With this device the signals sent out by an arc station closely resemble those from a large vacuum tube set. Only one wave length is sent out, no back wave is heard and the harmonics often accompanying the signals are much reduced. In addition the transmitted signals are unusually clear cut, as the sending relay does not have to break any current and so does not spark at the contacts on the sending side. All sparking occurs on the dummy antenna or non-radiating side of the relay stroke.

The arc transmitter, however, is not limited to its use in radio telegraphy. As a generator of continuous waves it can also be used for radio telephony. As far back as 1907 Poulsen himself telephoned from Denmark to England using an arc. In 1906 the United States fleet that made the famous trip around the world was equipped with arc type radio telephones. It is true that the latter were of early and crude design and construction and did not give entire satisfaction. They were later improved, however, and a very workable arc telephone set developed, good for perhaps 50 miles over water. As larger arc sets were developed, however, the telephone application was lost sight of for the reason that unsurmountable difficulties were encountered. The power was there of the kind suited for radio telephony, but no microphone could be devised delicate enough to properly reproduce speech that could handle enough current to take care of any but the smallest sets. This was because no trigger has yet been devised, for the arc oscillator, equivalent to the grid of the vacuum tube oscillator.

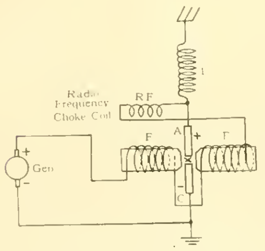

FIG. 4—TYPICAL CONNECTIONS OF AN ARC TRANSMITTER DIRECT CONNECTED TO THE ANTENNA

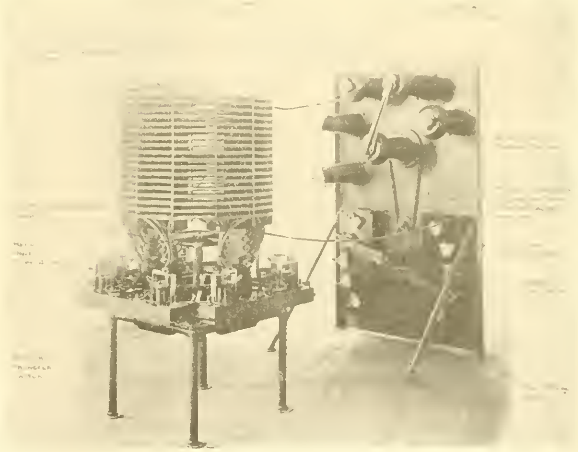

FIG. 5—ARC WAVE CHANGER AND INDUCTANCE SYSTEM

*Described by the inventor on page 114 of this issue.

Up to date it has been necessary, in arc telephone sets, to have the microphone modulate the power direct, by connecting it in series with the antenna or across the terminals of a coil coupled to the antenna, or in some other such arrangement. These methods work well but are limited in power by the amount of energy that the microphone can dissipate. Development work is now in progress seeking to perfect some new method of telephoning with arcs that will overcome this difficulty.

If an efficient and practicable method of telephoning with an arc transmitter is developed, the position of the latter will be greatly strengthened, even in competition with the larger size power tubes we can forsee in the not very distant future. The weaknesses of the arc type of transmitter are its lower efficiency, its emission of undesirable overtones and its lack of a flexible means of power control for telephony. To counterbalance this it can rightfully be claimed that improved methods of signaling give promise of eliminating the overtones, while its lower efficiency is counterbalanced by its low maintenance expense. As compared with the high-frequency alternator it is much cheaper in first cost, very much easier to repair, is susceptible to easy and quick change of wave length, can operate at shorter wave lengths and on smaller antennae, and has no high-speed moving parts.

As compared with the vacuum tube type of transmitter its maintenance cost is very much lower, and it has no fragile parts that require frequent renewals and which may not be readily available in remote locations. It also is available in much larger sizes than are yet practicable with tubes.

The majority of the large stations of the world are of the arc type, such as those at Annapolis, San Diego and Tuckerton U. S. A., Darien Panama, Pearl Harbor, Hawaii, Rome, Italy, Lyons France, and the largest station in the world, the new Lafayette station near Bordeaux, France.

Remote Control by Radio

A. L. WILSON
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When in 1884, Hertz made his momentous discovery that a Leyden Jar discharged across a small gap, caused a corresponding discharge across a gap made in a small loop of wire having no electrical connections, it was looked upon as a scientific novelty. The possibility of applying this knowledge to any commercial use, apparently, at the time, did not occur to anyone. It would have sounded like a story by Jules Verne if one could have recounted at that time the far reaching effects of this discovery. Few people of the time would have credited the phenomena with revolutionizing communication—indeed it was hardly considered possible that any form of wireless communication other than visual signaling would ever be accomplished.

The advent of the electrical telegraph did little to convince the general public or even the scientific man of the age that communication by means of electricity would become an every day necessity. When Marconi devised his first wireless telegraph, people, ever sceptical, looked upon it as the wild dream of a hair-brained inventor, although they had at this time adopted the telegraph and telephone. It was only after considerable difficulty and after having been turned down by his own government, that he persuaded the British Post Office Department to finance the building of his first experimental station. The Public looked on askance, thinking it was so much money wasted. What would have happened and what would people have thought if someone had suggested a machine, flying through the air, absolutely under the control of a wireless operator on the ground? Communication without wires; an interesting experiment but of what use could it be to the business man of the day?

And so at the present time, one does not realize the tremendous possibilities, the benefit which may accrue to the world of today a world ever on the watch for efficiency, speed and reliability, from the use of radio phenomena, in other fields than communication. The possibilities of radio control have been occupying the minds of inventors since the early days of the art, but there are so many variable factors which enter into the problem that, until recent years, very little progress was made. The world war probably had more to do in bringing radio into its present stage of development than would have been accomplished during many years of scientific investigation.

To the average individual, radio means "wireless telegraphy", or might also include "wireless telephony" and they would indeed be sceptical of any other uses to which it could be adapted. Communication, that is, of the straight message type, is but a small part of the radio field.

It has long been the dream of radio men the world over to devise an efficient and reliable means of attracting the attention of operators. Since the days of the filings coherer, it has always been necessary for the operator to wear a pair of headphones and continually search over a definite wave length range for incoming signals. Acoustic working presents marked advantages and enables faultless traffic to be maintained between two stations, but the disappearance of the coherer meant that there was no longer a simple accessory apparatus which allowed signals to be changed directly into a

strong mechanical movement, such as is necessary to ring a bell and thus call up a station.

One may think of the high power stations scattered throughout the world and conclude that the problem of getting a considerable amount of energy to the receiving station is one of comparative ease. Table I gives a comparison between transmitted and received energies in various types of electrical energy transmitting systems as given in authoritative text books.

Table 1—Power Received by Radio Equipment

	Watts Transmitted	Watts Received	Ratio
Power line	10^6	10^6	1
Cable Telegraph	1	10^{-3}	10^{-3}
Wire Telephone	10^{-2}	10^{-6}	10^{-4}
Radio	10^5	10^{-8}	10^{-13}

From this it would appear that, at the maximum range of the transmitter, the received power is measured in hundred-millionths of a watt. This power is ample to operate a modern radio head receiver, but even the most sensitive relay requires about one-thousandth of a watt to operate reliably.

In order to meet the demand for a calling device in the early days of the crystal detector, the Telefunken Company developed an instrument which would call up a station when the energy received was very small. This instrument consisted essentially of a very sensitive high-resistance galvanometer which could be de-

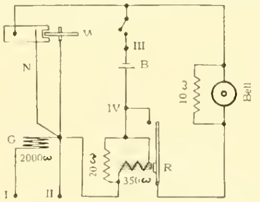

FIG. 1—SCHEMATIC DIAGRAM OF CALLING DEVICE

flected by the current from the detector. A suitable contact for working a relay cannot, of course, be made by the deflection of such a galvanometer needle, but the instrument was so arranged that when the needle deflected beyond a certain angle, it came into contact with a toothed wheel kept in slow rotation by clockwork. The needle then became engaged with the toothed wheel which carried the end of the pointer down onto a contact stud, and thus forced it into sufficiently good contact to complete a local circuit. This circuit operated a drop indicator, which in turn closed a circuit through an alarm bell which continued to ring until the operator released the needle.

The arrangement is shown diagrammatically in Fig. 1, in which *N* is the needle, and *W* is the toothed wheel seen in plan. The local battery is at *B*, and when contact is made the relay *R* operates and the bell rings. The terminals *I* and *II* are connected to the receiver apparatus in parallel to the high resistance phones, and the direction of the received current is so arranged that the pointer of the instrument moves to the right, that is towards the wheel. As soon as the sending instrument transmits a dash lasting about ten seconds the needle moves sufficiently to engage with the wheel, and is then rigidly held, so that the bell begins to ring.

The operation of the apparatus is very simple. When the terminals *I* and *II*, have been connected to the receiver and the terminals *III* and *IV* with the battery, the needle of the galvanometer has only to be unclamped for the instrument to be ready. The distance of the needle from the toothed wheel can be regulated and thus any desired degree of sensitiveness can be obtained. For ordinary working a distance of about one mm. is used. When the call has taken place and the bell rings, the clamped needle can be released and the apparatus is then ready for another call.

This same apparatus could be developed to operate any form of control systems. With radio control systems, however, there are serious difficulties to be overcome before they can be successfully applied to commercial use. Absolute reliability is essential and interference must be prevented. There are three main causes of interference, first, static; second, accidental interference from other stations; and thirdly, willful interference. Of the three, the latter is by far the worst, although caused chiefly by a spirit of mischief. There are a great many schemes which will overcome one or more of these objections, but relatively few which can claim absolute immunity from interference and at the same time be rugged and reliable. Codal selectors in themselves are not enough, neither can time element relays be used simply to prevent interference.

A system devised by the writer in 1916 can be applied to any form of control system and is practically immune from interference of all sorts. It consists essentially of a highly selective radio receiving set working in conjunction with a special transmitter. It is apparent that if the selector mechanism is entirely a part of the receiver, any transmitter can be adapted to operate it from a distance.

The system works as follows, it being understood that the whole operation is automatic. Supposing the control system has been applied to operate a sectionalizing switch on a power transmission line, or any other equipment which can be actuated by power from a local circuit established by the radio relay, the operator finding it necessary to open the sectionalizing switch, simply pushes a push-button switch in the power house. This starts the transmitting apparatus which sends out certain prearranged signals. These signals operate the receiving mechanism which, through suitable relays, opens the sectionalizing switch. The interference and other difficulties are overcome in the following manner:—

The transmitter is so arranged that it sends out a certain sequence of signals with a definite time interval between them, then automatically changing its wave length, it again sends out another sequence of signals, and can again change its wave length, if desired, for a

third or fourth sequence of signals. These signals being of a certain length of character and a definite time interval between them, the cycle of operations is completed in a definite time. At the conclusion of the cycle, the transmitting apparatus comes to rest and is ready for another operation. At the receiving end, the first impulse, in addition to rotating a selective switching arrangement, starts an escapement movement, which is previously set so that, unless the impulses are received at the correct moment, or the cycle of operations completed within the predetermined time interval, the receiver is automatically reset, at what might be called the zero point. The transmitter is shown diagrammatically in Fig. 2, in which S is a message wheel, having the signals and proper spaces cut in the periphery. This wheel is automatically rotated one complete revolution, (or more as desired according to the setting of the receiver time element) when the push button switch is operated, making or breaking contact with brush C_2. This brush, closing the circuit through R_1, operates the radio transmitter proper and causes impulses to be sent out. The radio apparatus is shown for clearness only as a spark transmitter, power being supplied to terminals I and II, T being the transformer, F the spark gap, D the condenser, O the oscillation transformer, A the antenna and G, ground.

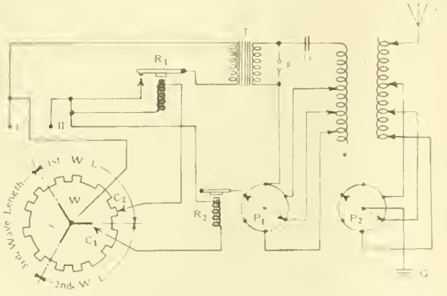

FIG. 2—RADIO TRANSMITTER FOR REMOTE CONTROL

Rotating with what may be called the "message" wheel is the wave change operating wheel W, which makes contact with brush C_1, closing the circuit through relay R_2. This relay, by a pawl-ratchet motion rotates the two wave changing switches P_1 and P_2.

The system lends itself to considerable changes which may be quickly made, allowing for the control of different switches or other apparatus without interfering with the other parts of the system. For instance, different message wheels could be used for each switch or the wave length clips could be moved, thereby using different combinations of wave lengths, or a different number of wave lengths could be used, or a combination of all these changes.

The receiver is shown diagrammatically in Fig. 3, in which A is the antenna and G ground, in series with which is the condenser V and inductance L_1. The circuit shown is a simple regenerative detector and two step amplifier, in which D is the detector bulb, A_1 and A_2 the amplifier bulbs and T_1 and T_2 the intervalve transformers. Instead of a headphone being connected in the plate circuit of the last amplifier bulb, as is the usual practice, a sensitive relay is used, the operating coil of this relay being connected to "message" wheel M by means of brush C_2. In the "zero" or off position of this wheel, brush C_2 is in contact with the first impulse contact on the wheel, thus permitting the first impulse received to operate the relay R_1. This relay is in series with the time element control and releases the escape movement, which also rotates the message wheel M. It will be seen that unless the signal is received at the proper instant, the message wheel will be in a neutral position with respect to the brush C_2 and no impulse will be received. In the time element T is a duplicate of the message wheel, acting on the escapement in such a way that, unless a signal is received at the correct interval, the whole mechanism returns to zero and will require a complete cycle of operations to be effective.

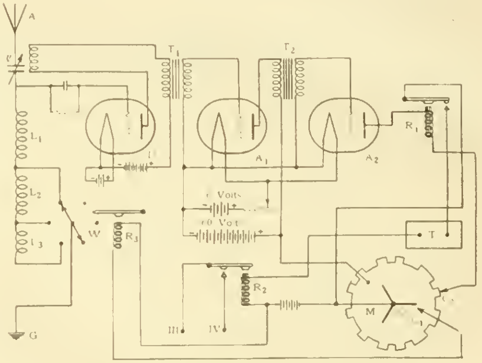

FIG. 3—RADIO RECEIVER FOR REMOTE CONTROL

Rotating with the message wheel is the wave changing wheel Q making contact with brush C_1, which completes the circuit through the operating coil of relay R_3. This relay operates the wave changer switch, shown simply as increasing the turns of the inductance in the antenna circuit. These extra turns are shown as L_2 and L_3. The relay R_2 closes the final circuit of the controlled apparatus which is connected to terminals III and IV.

This system is applicable to any apparatus which is desired to control from a distance by means of radio, and the switching operations effected by the local circuit can be made as complex as required, without sensibly affecting the comparative simplicity of the apparatus.

The radio transmission of power would revolutionize traction and industry. The metering of such power might tax the ingenuity of meter engineers, but undoubtedly this could be overcome. The future applications of the art are as impossible to conceive as were the present developments of Hertzian waves.

Education of Radio Engineers

Communication Engineering at Yale

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Assistant Professor of Electrical Engineering
Yale University

MAXWELL'S mathematical deductions communicated to the Royal Society in 1864, predicted the propagation of electromagnetic waves at finite velocity. However, this beautiful theory lacked experimental confirmation. In 1888 Hertz, after several years of intentionally directed effort towards an experimental verification of Maxwell's electromagnetic theory, established the proof and laid the foundation of radio engineering. It is said "There is not in the entire annals of scientific research a more completely logical and philosophical method recorded than that which has been rigidly adhered to by Hertz in his researches on the propagation of electric waves through space." As a result of the imagination of these men and their ability to visualize, it is now possible to communicate between any two places regardless of whether they are on land, ship, airplane or submarine.

If our universities are to produce radio engineers of vision, capable of the highest scientific attainments, who will in time extend the boundaries of our present knowledge, the imagination must be developed. Lest the students become discouraged by the wonderful progress that has already been made, attention is called to the fact that each new development opens up innumerable opportunities for improvements, inventions and discoveries and these in turn reveal other undeveloped fields. The student little appreciates the many fascinating problems that are yet to be solved. He senses but vaguely the opportunities that are his.

During the war the Signal Corps of the United States Army required competent radio engineers and radio officers, and a large number of men who were familiar with the operation of telephone and radio apparatus. Many schools were established for training radio officers and operators, one of which was moved to Yale in the summer before the armistice. The original plan was to send to the school 100 picked men each month for a three months' course, making the normal attendance 300. At the time of the signing of the armistice there were nearly 500 officer candidates in training. The Government sent a number of competent officers and a large supply of both indoor and field apparatus for instruction. After the armistice the Signal Corps arranged to continue a group of officers at Yale for advanced training in communication engineering with particular reference to radio. Much of the equipment supplied for the earlier instruction remains and additional apparatus has been supplied by the Government. This serves for the advanced instruction of officers and others in the graduate courses. It is also available in undergraduate courses and in instruction of the students who have enlisted in the R. O. T. C. Signal Corps group. Instruction in the latter group is given by a detailed officer of the Signal Corps and the apparatus is regularly cared for by Government custodians detailed for the purpose.

In addition to the equipment supplied by the Government, there is available the equipment of the electrical engineering laboratory and of the physics laboratory to which recent additions have been made. Furthermore, the communication companies have loaned special demonstration apparatus. All these factors contribute to a complete and up-to-date equipment for instruction in communication engineering.

The course of instruction, based upon broad fundamental principles underlying the generation, propagation and utilization of electromagnetic waves, is administered in such a way as to develop the student's analytical power. In order to deal quantitatively with this subject, it is necessary to use mathematics, which is nothing but a rational, systematic and scientific way of expressing physical truths or relations between physical quantities where measurements of relative magnitude are involved. The mathematical analysis of communication engineering problems is a powerful aid for directing the mind towards the correct solution, for developing the deductive and reasoning faculties, and for testing the accuracy of one's knowledge. A reference to the literature of the subject will convince the student and engineer of the importance of this phase of his training. While it is necessary for the student to acquire facility in handling mathematical expressions, it is even more important that he be able to interpret these mathematical expressions in terms of the physical phenomena and to express the physical phenomenon in equational form for the purpose of computation. In other words, the purely symbolic or sign language of the mathematician is made a vital, living language of the engineer, expressing definite, understandable physical relations with which he is concerned.

The theoretical and experimental study of circuits and equipment are so intimately related that the student acquires familiarity with the phenomenon and confidence in his ability to predict with precision the results to be obtained, when the conditions of a problem are specified. Much depends upon a good laboratory course where practice and the rigid requirements of theory are brought into harmony. One experimental means of giving the student a definite understanding of the action in radio circuits is a synchronous switch used

with the oscillograph in connection with the experimental study of transient electrical phenomena, so that a change in any of the circuit conditions may be instantly observed on the screen of the oscillograph. This switch makes it possible for the student to observe upon the screen the effect of a variation in R, L or C upon the frequency and decrement of simple oscillatory circuits; of variation of coupling between primary and secondary of coupled oscillatory circuits; of detuning; of introducing resistance in either primary or secondary; of impulse excitation; of quenched gap action; of connecting any type of circuit across an alternating electromotive force at any desired point of the wave, which may be varied uniformly from 0 to 90 degrees while making an observation; of starting currents in the transformer where the operator controls the point of closing the circuit and also the amount of residual magnetism in the transformer; etc. This gives the student an insight into transient electrical effects and the operation of radio circuits of permanent value. Special emphasis is placed upon the preliminary study of the phenomena on the screen before taking oscillograms for the purpose of computation and record. The theory is experimentally verified the same as that of periodical alternating current. However, greater precision is possible and each experiment is subjected to a rigorous mathematical analysis. The students study the different types of radio equipment in the laboratory and also in the field.

Westinghouse Technical Night School

W. W. REDDIE
Director,
Electrical Department, W. T. N. S.

THE Westinghouse Technical Night School, fostered by the Westinghouse Electric & Mfg. Company, offers young men who must earn their living during the day time, an opportunity to study the fundamentals of engineering while they see the principles and theory studied, applied in their daily work. It offers young women an opportunity to fit themselves for responsible positions in the commercial world and in the community. The training in the engineering school is not specialized, but is general and provides an excellent foundation in shop practice, mathematics, mechanics and the fundamental principles of steam and electrical engineering. The student obtains that thorough knowledge of fundamental principles which, when applied in practice, result in skill in any chosen line. The Night School aims to develop character and make men more useful to their fellowmen, both socially and technically.

The School benefits first, the student himself, by giving him training which enlarges his vision, and enables him to gain more of success, by whatever standards that success may be measured; second, it benefits industry, in that the skill of the student is increased and his ability developed by technical training; third, it benefits the community, in that a more useful citizen is made by the training given. Correspondingly, three sources of revenue maintain the school. First, the student pays a tuition; second, industry contributes to the support of the school through appropriation; and third, the community contributes through public school co-operation. The classes are conducted in the public school buildings of the neighboring communities. Many students enroll in the Night School courses who, through force of circumstance, have left the common schools after passing the eighth grade, or even before. These students, working in the shops and factories during the day-time, carry on their studies in the evenings and are able, in the course of time, to enjoy the opportunities, rewards, and success open to the trained man.

The curriculum includes Foreign, Preparatory, Engineering, Post-graduate, Extension and Women's Departments.

The foreign born resident, unable to speak, read or write English can enter the Foreign Department and by diligently and conscientiously following his studies for eight years, progressively pass through the Foreign, Preparatory and Engineering Departments of the Night School and graduate with a working knowledge of the fundamental principles of engineering. This statement, of course, pre-supposes that the student has had some public school education in his native land. A number of the alumni of the school have passed through these departments and their subsequent success has been a credit to the school.

Generally, students who have completed the eighth grade of public school work, are admitted to the Engineering Department, although all applicants are given a thorough oral examination to check their knowledge of the mathematics that should be obtained in the public schools. Students who have not completed the eighth grade or who do not qualify by oral examination, are required to take preparatory work, which may extend over a maximum period of two years.

Work in the Engineering Department covers a period of four years of thirty-six weeks a year, three nights of three hours each per week. The total number of school hours, recitation and laboratory work thus amounts to 1,200 hours. A student will average about 1.5 hours outside study for each hour spent in school so that the total number of hours spent in self-development during this four-year period will be from 3000 to 3300 hours for the average student. Table I shows the

percentage of time devoted to various branches of the Engineering Course. It is interesting to see that [illegible] percent of the total time is devoted to [illegible] subjects while [illegible] percent of the time is given to the theory and practice of direct and alternating current electricity.

The school is equipped with electrical, chemical and physics laboratories and the courses are arranged to correlate and coordinate the class room work and the laboratory work. Increasing enrollment necessitated maximum utilization of available space. The electrical laboratory, as an example of this, is partitioned into four compartments, two for alternating-current and two for direct current work. A common power relay serves the four compartments and in order to provide maximum free floor space all switch gear, meter boards, and rheostats are mounted on the partitions, as shown in Fig. 1.

FIG. 1—ELECTRICAL LABORATORY

Another example of efficiency practiced, as preached to students, is found in the utilization of class rooms. Five minute physical drill led by one of the class, is given between periods, in order to provide the necessary intermission and relaxation between recitations.

The post-graduate course was established in [illegible], and courses in radio engineering, industrial economics, electrical machine design, laws and contracts in engineering, and practical calculus are offered to the alumni of the school and others who are interested in the advanced classes.

An Extension Department is being developed for the benefit of employees of the Westinghouse Company, in cities where service departments are located. [illegible] courses are open to all employees who wish to take them. [illegible] has been started in [illegible], and New York, Buffalo, Atlanta, [illegible] will be [illegible] in the near future.

The [illegible] Department [illegible] a two year course [illegible] the dictation courses are planned so that students may apply the work studied in school to their everyday work in business and engineering offices.

All classes are conducted by men who are actively engaged in practical work and who are specialists in their particular lines. They have for the most part had a technical education followed by wide experience and broad training, and are thus well able to judge the kind of men needed in the industrial world, and to develop the students accordingly.

The methods of instruction would hardly be expected to check with methods of instruction in general use in the day colleges and schools. The aim is to teach the students the principles, which are the tools with which they must work in solving problems which they will be called upon to solve. The applications of these principles are pointed out and practice is given in using them. The thought, always before the instructor, is that he must assist the student to translate the theory and principles studied, into the efficient utilization of men and materials in the manufacture and application of machinery.

The work in the drawing room, pattern shop and foundry is carefully correlated to give the student an idea of the relation of theory to practice, and to familiarize him with the processes of manufacturing machinery. [illegible] projects are carried out. The student makes drawings in the drawing room for the pattern which he makes in the pattern shop. Later he makes castings and [illegible] from these same patterns which he has followed through from their conception.

The courses and class-room work are planned to stimulate the student to independent thought. The doctrine of the instructor is that unless a student can be taught to analyze, assemble the facts and combine them to form logical conclusions, the instruction given is of more or less temporary character.

The laboratory courses synchronize as far as possible with class-room work and all courses are co-

FIG. 2—WESTINGHOUSE TECHNICAL NIGHT SCHOOL ENROLLMENT BY YEARS

ordinated in such a manner that the relation and application of algebra, geometry, and trigonometry, for example, to their practical use and application in engineering problems is kept before the students. The ideal of a W. T. N. S. instructor is to graduate a student who:—

1—Knows the fundamentals of theory he has studied.

2—Knows where these fundaments fit in with the design and manufacture of electrical machinery.

3—Knows the application of every machine he has studied and the why of it.

4—Knows where to look for knowledge that he does not have.

5—Has a working knowledge of the generation, distribution, control and utilization of electrical energy.

6—Is capable of attacking problems within the scope of his development.

7—Grasps and can apply the principle that economy dictates for most designs and applications of machinery; that economy in choice and use of materials, efficiency in the labor of assembling and working the materials, efficiency in the generating and application of power, all combine to turn out more work at less cost.

The nature of the work carried on at the Night School has involved the preparation of several texts which particularly fit the methods of instruction used. Among these texts are included an Industrial Speller, Shop Problems, Physics Notes, Mechanics Notes, Notes on Metallurgy, and a set of Engineering Problems which involve the application of electricity, physics, chemistry, steam, and mathematics to practical problems of design, manufacture, distribution and operation.

A Students Association, of which all students are members, regulates all outside school activities and has developed an excellent school spirit. The Association elects its own officers who, with the class presidents, constitute the governing body. This governing body manages the student affairs and exercises control over the students through the class presidents. The Students Association maintains football and basketball teams and conducts the Annual Banquet which is attended by 500 to 600 students. This gives the student leaders an opportunity to gain experience in managing business affairs. Much of the success of the Night School has been due to the ideals of the founders and the leaders who have been associated with the school.

TABLE I—ENGINEERING DEPARTMENT—DISTRIBUTION OF HOURS

4 Years—36 Weeks Per Year—9 Hours Per Week—Total Hours 1296

Year	Term	Mechanical Drawing	Shop Work	Mathematics	Physics	Business English	Electricity	Chemistry	Steam	Metallurgy
Fresh	I	36	Foundry 36 Pattern Shop 36	Shop Problems 54						
	II	108		Algebra 54						
Soph.	I		Machine Shop 108	Algebra 54						
	II			Geometry and Trig. 54	108					
Junior	I			Mechanics 36	54	36	D. C. 36			
	II			Mechanics 36			D.C. and A.C. 90	36		
Senior	I			Engineering Problems 36			D.C. and A.C. 90		36	
	II			Engineering Problems 36			A. C. 54		36	36
Total Hours per Branch		144	180	360	162	36	270	36	72	36
Percent. of Total		11.1	13.9	27.8	12.5	2.78	20.8	2.78	5.56	2.78

The Regenerative Circuit

EDWIN H. ARMSTRONG

EDWIN H. ARMSTRONG'S contribution to the radio art, particularly the vacuum tube radio art, is epoch making. No one who has empyoyed his feedback or regenerative circuit can fail to appreciate its eminent value and inexhaustible possibilities. Armstrong made his invention when he was about 21 years of age and before he graduated in the Department of Electrical Engineering at Columbia University in 1913. Although the original discovery was more or less accidental, Armstrong soon appreciated the real meaning of it and applied it to the construction of the vacuum tube oscillator, which is more easily and accurately controllable than any other oscillator in existence. The regenerative receiver and the regenerative oscillator will always figure among the classical inventions and will occupy a foremost position in the research laboratory, as well as in the commercial wireless service. It entitles Armstrong to a very high place among electrical inventors.

When I was in Paris in the Spring of 1919 I met General Ferrie, the Chief of the Signal Corps of the Allied Armies. Armstrong was working under him. The general paid me several well meant compliments which I refused to accept on the ground that I had done so little for his Signal Corps. "Ah, Monsieur le Professeur" exclaimed he, "but have you not given us Armstrong."

—PROF. M. I. PUPIN.

THE question as to how the invention of the regenerative or feed back circuit came about can best be answered by the statement that it was the result of a streak of luck—and the kind of luck that comes once in a lifetime. For, all things considered, the operation of the regenerative circuit involves too many new phenomena, inextricably woven together with the operation of the audion, a device whose action was clouded in the mystery of the DeForest gas ionization theory at the time the invention was made, for any one seriously to lay claim to a mental pre-conception of the operation of the feedback method of amplification and oscillation.

The invention was the result of an idea—the kind of idea which may be best expressed in the form "what would happen if" certain additions should be made to existing apparatus. The resulting trial of these additions uncovered a series of new phenomena based on a new principle. The discovery came out of a desire to find out exactly how the audion detector detected—not an easy thing to do in the dark ages of '11 and '12 when the very scanty literature on the subject explained (without explaining) that the action was due to ionized gas, and the audion was known to the art simply as a detector of high frequency oscillations.

To find out exactly what went on in the tube, I started an investigation. This was carried on under considerable difficulty, since my main object in life just then was supposed to be the obtaining of the degree of Electrical Engineer at Columbia University, and the professors could not be relied upon for the necessary charity mark of 6 unless a certain so-called reasonable amount of time was devoted to their particular courses.

However, during this investigation it was observed that a condenser placed across the telephone receivers in a simple audion receiver sometimes gave an increase in signal strength; not much of an increase, but nevertheless a very definite increase, and with only a small value of capacity. Now I had tried a condenser across the phones many times before (what amateur has not, when graduating to the audion from the crystal detector stage, where telephone shunt condensers originated) but never before had there been any observable change in signal strength.*

The small condenser indicated strongly the presence of high frequency oscillations in the plate circuit, and I thought about it a great deal without being able to account for their presence there in any satisfactory manner. During the summer vacation that year, an idea was suggested by the fundamental axiom of radio, "wherever there are high frequency oscillations tune the circuit," and the idea was to see what would happen if the plate circuit of an audion detector should be tuned by means of an inductance.

All the old timers remember *C.C.* later known as *M.C.C.* and *W.C.C.*, the Marconi press station at Wellfleet, Mass. This station was the one hundred percent reliable testing standby of all experimenters, and on *M.C.C.* the first test was made. A standard audion detector system was set up and tuned in, and a tuning inductance introduced into the plate circuit of the audion. Then various things began to happen. As the plate inductance was increased, the signals were boosted in strength to an intensity unbelievable for those days, the more inductance the louder the signal, until suddenly the characteristic tone of *M.C.C.*—the tone which any of the old timers, if they heard it on Judgment Morn, would recognize instantly—disappeared, and in its place was a loud hissing tone, undeniably the same station, but recognizable only by the characteristic swing and the

*The reason for the increase in signal strength obtained when the telephone receivers in the simple audion circuit are shunted by a condenser, remained unknown for a number of years. The explanation is an interesting one—the ordinary audion circuit is not a neutral device as regards reaction between the plate and grid circuits. There is a reaction which is in the opposite sense to the regenerative reaction; that is, the plate circuit robs the grid circuit of energy. This is because of the capacity reactance of the telephone receivers. When this is decreased by a parallel condenser the signal strength increases.

messages transmitted. A slight reduction of the plate inductance and the old tone was back again,—and then the placing of the hand *near* a tuning condenser and the hissing tone reappeared. It required no particular mental effort to realize that here was a fundamentally new phenomenon, as obscure as the principle of the operation of the audion itself, but which opened up an entirely new field of practical operation.

Here the element of luck ended and it became simply a case of a lot of hard work, digging out the meaning of the various phenomena. A long series of experiments was carried out on different wave lengths and with various circuit modifications, and it became possible on a small amateur antenna to receive readable signals from the navy shore stations on the Pacific coast, the Manoas and Porto Vehlo stations in Brazil and the Marconi transatlantic station at Clifden, Ireland, with regularity every night, a performance which a few months before was undreamed of. But while the method of producing these results was known, many of the phenomena involved were as obscure as ever. The most striking of the various phenomena was, of course, the change of tone and the investigation centered on this. A number of things contributed to the suspicion that the hissing state was due to the production of local oscillations by the system. With this idea and the aid of some instruments borrowed from one of the university laboratories, it was a relatively simple matter to determine that this was actually the case. Once it was apparent that the system was capable of generating oscillations, the explanation of another phenomenon became plain. I had observed on a number of occasions during the course of listening to various stations, that a whistling note would frequently appear in the telephones, which could be varied by adjustment of the receiving apparatus. I observed this particularly in the course of listening to a wireless telephone station. After the discovery of the generating feature of the system, the explanation of the change in tone became apparent—the system was acting as a heterodyne receiver.* A series of tests confirmed this explanation.

That is briefly the story of how the invention of the feedback circuit came about, and how its properties of acting as a generator and a self-heterodyne were discovered. Since that time a vast amount of work has been carried out in investigating in detail the precise manner in which the various phenomena occur and in determining quantitatively the amplification given by the circuit in both the non-oscillating and oscillating state.

Without considering the actual mechanism of the operation of the system let us consider the physical results accomplished in practice. Consider first the results in the non-oscillating state. Measurements of the signal energy in the telephone receivers show that an amplification of from 100 to 1000 results from the regenerative action, the value depending on the strength of the incoming signals, the greater amplification being obtained on the weaker signals. By reason of the nature of the amplification, which is of the negative resistance type, the selectivity of the system is greatly increased, the gain in selectivity becoming more pronounced the lower the damping of the incoming wave. Three distinct operations are therefore carried on simultaneously in the non-oscillating state. *1*—the high frequency currents are regeneratively amplified; *2*—the selectivity of the system is increased; *3*—the amplified high-frequency currents are rectified and converted into currents of telephonic frequency.

When the amplification is increased beyond a certain limit the system passes into the oscillating state and generates, in radio circuits, high-frequency currents. In this state it is applicable to the uses of any generator, and because of its simplicity and reliability it is particularly applicable to the heterodyne receiving system. By far the most interesting application is that of the "self-heterodyne" in which the same circuit and tube perform simultaneously the functions of generator of the local frequency, amplifier of the incoming high frequency and rectifier of the beat current to produce currents of audible frequency in the telephones, at the same time giving the increase in selectivity inherent in regenerative amplification. All these operations go on simultaneously in the same system with a single tube and out of it all comes a signal 5000 times as strong as the signal given by a simple audion circuit with a chopper, and far less subject to the disturbing influence of static and interfering signals.

On account of the very fortunate combination of sensitiveness and simplicity, its effect on the art was immediate. The amplifying feature made possible transoceanic signaling. The self-heterodyne feature contributed very largely to the change from spark to continuous wave systems. The generating feature has been responsible for the development of carrier wave or wired wireless signaling. And this progress can be attributed, not to any carefully preconceived ideas, but to the versatile properties of the regenerative circuit and the luck that led to its discovery.

*Diagrams and a description of the operation of the regenerative circuit are given in this issue, p. 140

The Journal Question Box

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

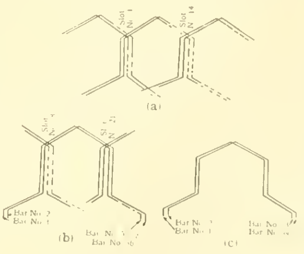
To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1982—Reconnecting Induction Motor—I have been using the tables of A. M. Dudley, and recently I had a pair of motors to be changed from three to two-phase, at the same voltage, namely 220 volts. They were four pole motors with 1750 r. p. m. at full load on a 60-cycle circuit. They were connected two parallel star, and had 54 coils. According to the tables they will not reconnect for satisfactory operation on two-phase at the same voltage, but another electrician, connected them in two parallels and cut out two coils and they claim that the change is giving satisfactory results. Now what I want to know is this, just what is happening in those motors and what are their new operating characteristics. T.I.M. (PA.)

The two coils were cut out so that there would be no circulating currents due to uneven number of coils in the parallel circuits. This increased the field strength in the ratio of 54 to 52. When using the same winding and changing from three-phase to two-phase, the voltage should be reduced in ratio of 1 to 1.22 or the number of coils increased in the same ratio when the same voltage is used. From this, the motor is now connected with a field $54/52 \times 1.22$ or 1.27 times as strong as before. This will increase the core loss and pull out torque and decrease the power factor and efficiency to lower values than before, depending on the saturation and the distribution of losses in the motor. The practice of cutting out coils is not recommended for first-class work, but can be done to advantage in emergency where time and service are of more value than performance. C.W.K.

1983—Armature Connections—Given, a 25 hp, shunt motor, 110 volt, 300 r. p. m., number of slots = 80, number of commutator bars = 160, number of poles = 6, thickness of brush = 2 commutator bars, coils formed of two separate single-turn coils placed in slots 1-14 giving four conductors per slot as in Fig. (a). I judge such a winding to be a duplex wave winding and the proper method of connections to commutator to be as in Fig. (b). Kindly indicate if assumptions in Fig. (b) are correct. What would be the effect if, instead of connecting as in Fig. (b) the connections were made as in Fig. (c). The above remarks refer to a motor, which has recently been rewound. At no-load the motor runs at a speed about four times that on name plate and current seems to be excessive. I am unable to state the action of motor under load. All connections to field, etc., seem to be correct but I am doubtful of the armature connections which are made as in Fig. (c). C. S. (QUEBEC)

The winding connected as in Fig. (c) has 8 current paths, consisting of four independent two circuit windings. One starts at bar *1* goes in succession to bars 53, 105, 157, etc., finally closing on itself after connection to only one-fourth of the total bars. Other circuits from bars *2*, *3* and *4* do the same. The winding as connected in Fig. (b) has four current paths, consisting of two independent two circuit windings. One starts at bar *1*, goes in succession to bars *55*, *109*, *163*, etc., finally closing on

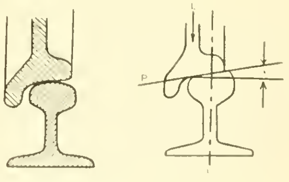


Figs. 1983 (a), (b) and (c)

itself after connecting to only one-half of the total bars. An independent circuit starting from bar *2* does the same. If the commutator connection is 1-54-107-160 etc., the winding will be a simple two circuit winding. Since the speed, when connected as per Fig. (c), is four times the rated; and since the speed would be approximately inversely proportional to the number of current paths, it is evident that the original winding was a simple two circuit winding, and that the armature connections should be 1-54-107-160. Reconnect it in this way. When connected as per Fig. (c) the no-load current would be excessive, partly due to higher no-load losses at the higher speed, and also because probably there would be some circulating current between the various circuits. Also the brushes are not wide enough for the winding shown in Fig. (c). M. S. H.

1984—Car Wheels, Rails and Brakes—Has the experiment of shaping car wheels and rails to fit one another as shown in Fig. (b) ever been tried, and with what success? Is the coefficient of friction between a wheel and a rail less when the area of contact is small as in Fig. (a) than it is when the area is large? Does a narrow flangeway in a brake shoe unduly grip the wheel and cause it to slide, even when the radial brake shoe pressure is moderate? G. F. S. (MASS.)

Better results have been obtained with the conical tread car wheel shown in Fig. (a), both in experiments and actual practice than with car wheels shaped to fit the rails or vice versa. Tread coning practically compensates for the increased length of the outer rail on curves. As the outer wheel flanges crowd against the rail, the inner wheels travel on the smaller diameter. When treads become grooved, or when the coning is worn down, the wheels should be trued on a lathe or discarded. Grooved wheels cause derailment on frogs and increase tractive resistance on curves. The coefficient of friction is approximately independent of the area of contact, except in cases of fibrous materials, in which case the coefficient increases with area of surface contact. The coefficient of friction, however, is materially affected by the pressure, speed, degree of smoothness and condition of the surfaces, temperature, etc. With car wheels, rails and brakes it is a question of safety, expense and wear, since the coefficient of friction is practically independent of the area of contact. The principal objection to shaping the rail to fit the conical tread of the wheel, as shown in Fig. (b), is the increased danger in spreading the rails. After rails have been in service for sometime they gradually wear down to this form and it is common practice to change the rails about or replace them. It is quite obvious that, with a rail in such a condition, when the flanges of the wheels on one side crowd against the rail, the center of pressure on the other rail, falls inside of line *C* drawn through the center of the rail; furthermore a force *P*, the horizontal component of load pressure *L*, due to angle *a*, tends to push the rail outward. The narrow flangeway in the



Figs. 1984—(a) and (b)

brake shoe is not designed to grip the wheel so as to cause it to slide. The moment the wheel slips the coefficient of static friction ceases to act and its place is taken by a very much smaller coefficient of sliding friction. The flangeway increases the wearing surface and the life of the brake shoe. As the brake shoe wears away quite easily, all gripping effect of the flangeway soon disappears. M. M. B.

1985—Permanent Magnets—About how much is the flux density per sq. in. in permanent magnets, such as used in watthour meters? E. S. (MICH.)

The strength is approximately 25 000 lines per sq. in. The strength varies with the different types and with individual magnets of the same type. A. R. R.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

APRIL 1921

First Aid for Electrical Injury

In and about the shops and car barns of electric railways there is always present the danger of injury to employees by being burned or shocked by electricity from the trolley or third rail, or from the various test circuits used in connection with the overhauling and repairing of the equipment. Such accidents as the result of carelessness or ignorance will happen in spite of the many safety-first precautions, and first aid helps should be provided that will relieve suffering and in some cases may save a life.

The importance of this work is fully appreciated by some of the larger operating companies who have established special medical departments in charge of a trained attendant, which are located in the shops as a part of their organization. To the smaller companies who cannot afford to maintain such a department, the following suggestions are made to provide the fundamentals to take care of emergency cases of accidents due to electrical injury.

FIRST AID CABINET

In order to take care of surface burns such as result from coming in direct contact with an electric arc or flash of any kind, a first aid cabinet, such as shown in Fig. 1, can be secured and maintained at a nominal cost. This cabinet contains the necessary material to give first aid to burns and other injuries and in addition has simple remedies for cramps, headaches, etc. The size and equipment of this outfit can be modified to suit local conditions. It should contain the following equipment:—

FIG. 1—FIRST AID CABINET

Bottle of carron oil* (equal parts linseed oil and lime water); bottle of aromatic spirits of ammonia; bottle of gasoline; bottle of liquid soap; bottle of cramp cure; bottle of tablets for cold; bottle of tablets for headache; bottle of iodine; bottle of eye wash; medicine dropper; rolls of cotton; bandages; adhesive plaster; pair of scissors; tourniquet; small basin; paper spoons; paper cups.

TREATMENT FOR SURFACE BURNS

The following gives briefly the steps to be taken in rendering first aid to such injury:—

1—Wash the injured part with gasoline until thoroughly clean.

2—Apply the carron oil, or treated vasaline, on a piece of gauze and apply to the burned member.

3—Wrap carefully with the gauze bandage.

4—Secure bandage by means of small strips of adhesive plaster.

*Another very good lotion for burns is vaseline with 5 percent bicarbonate of soda.

RESUSCITATION FROM ELECTRICAL SHOCK BY MEANS OF ARTIFICIAL RESPIRATION

It sometimes happens that the workman gets in contact with an electric circuit and is badly shocked. In this case quick action is necessary. For this reason, every employe should be able to apply artificial respiration at once, as any delay is dangerous. Such accidental shocks seldom result fatally if the victim is aided immediately and the efforts at resuscitation are continued. If the body is in contact with the live conductor, a dry stick of wood or a dry piece of clothing should be used to remove the conductor or roll the body to one side. If the body is in contact with the earth, any loose or detached piece of clothing may be seized and used without any danger to draw the body away from the conductor.

Summon the doctor without delay.

DIRECTIONS

1—The man is laid upon his stomach, face turned to one side so that the mouth and nose do not touch the ground.

2—The patient's arms are extended above his head. His mouth is cleaned of mucus, blood, serum, tobacco, chewing gum, false teeth, etc., by a stroke of the finger.

3—The operator kneels, straddling the patient's hips and facing his head, as shown in Fig. 2.

FIG. 2—APPLYING ARTIFICIAL RESPIRATION

4—The operator places his fingers parallel, upon the lowest ribs of the patient, and throws his own body and shoulders forward, so as to bring his weight heavily upon the lowest ribs of the patient. This downward pressure should occupy about three seconds, then the pressure is suddenly released for two seconds without removing the hands. Squeezing out the air in this manner creates a partial vacuum, and on release of pressure the air rushes into the lungs, due to the elasticity of the chest walls causing the chest to expand.

5—Repeat this act at the rate of about 12 times a minute—the danger is that in the excitement of the occasion the rate will be too rapid. If the operator is alone with the patient, he can adjust the rate of the artificial respiration by his own deep regular breathing; if others are present, a watch can be used to advantage to regulate the rate. In all cases the efforts at resuscitation should be continued at least 1.5 to 2 hours or until the arrival of the physician, who should be summoned at once. Any evidence of returning breathing should encourage the operator to continue his efforts. Such efforts are usually successful within 25 minutes, but recoveries have occurred after more than two hours unconsciousness.

6—While the artificial respiration is being carried on a second party may pull the hair, dash cold water in the face, loosen the clothing and collar, and hold a cloth saturated with aromatic spirits of ammonia near the nose. Inflicting pain, such as pounding the soles of the shoes, with a board, slapping and rubbing the arms and legs, pulling the tongue, or the hair, have a quickening effect.

7—No stimulants nor liquids of any kind should be given by mouth while the patient is unconscious.

8—Keep back the crowd, let the patient have air.

JOHN S. DEAN

THE ELECTRIC JOURNAL

VOL. XVIII MAY, 1921 No. 5

The National Electric Light Association

MARTIN J. INSULL
President,
National Electric Light Association

THE 44TH ANNUAL CONVENTION of the National Electric Light Association will meet in Chicago from May 31st to June 3rd inclusive. At this Convention will be outlined and discussed ways and means for promoting the purpose of the Association "to advance the art and science of the production, distribution and use of electrical energy for light, heat and power, and for public service." In carrying out this purpose the Association has always received the assistance and advice of the leaders in the industry. During the present administrative year the work has been carried on as heretofore by the general and special committees of the accounting, commercial, public relations and technical national sections of the Association under the immediate direction of their respective organizations and the general direction of the Association's Public Policy and Executive Committees and the headquarter's staff. In general the work of the National Sections covers all branches of the industry, not only as to its immediate necessities and to the ever-increasing variety of use for electrical energy but for a more efficient public service and a far greater development of the industry in the future. These matters of so vital importance to the commercial and social development of the nation will be fully reported on and discussed at the coming Convention. During the life of the Association not only its members but also the public have benefited by its work. It has attacked and solved the problems that have led to greater efficiency in the production and distribution of electrical energy with a consequent improvement of service at a decreasing cost; the more general application of electrical energy to the nation's business and home life, with a consequent development of the necessary appliances. The merchandising of these appliances has been studied until through the various branches of industry, including manufacturers, jobbers, contractor-dealers and Central Stations, these labor saving devices and electric service are daily brought to the business and home life of the nation.

Through its work, the Association has been one of the factors in developing the industrial productivity of the country and the comfort of its citizens. By the development of transmission and distributions systems the country is surely and rapidly being covered by a network of lines carrying electrical energy to the smallest hamlet and giving to it the same class of service that was enjoyed only by the larger cities a few years ago.

MARTIN J. INSULL
Vice-President
Middle West Utilities Company

During the previous administration, President Ballard, vice-president and general manager of the Southern California Edison Company, brought to the Association the vision and energy of the great West. Through his efforts the activities of the Association were largely increased and expanded with additional benefits to the public and the industry. The establishment at headquarters of a service department, a publicity department and an engineering department added greatly to the service that the Association was giving to its members. The partial de-centralization of the work by the creation of thirteen geographic sections was arranged for and put into effect. This enables the several sections of the country, having problems peculiar to themselves, to work actively toward their solution as well as to carry on in their geographic division the general activities of the Association. The creation of the new national public relations section to bring about a better understanding between the public and the industry was formally authorized at the Pasadena Convention. Since that time Mr. M. H. Aylesworth has been appointed executive manager of the Association to take active charge of working out these new plans under the direction of the public policy and national executive committees of the Association. To the best of its ability the present administration has en-

deavored to carry out these plans and policies inaugurated by President Ballard and which have met with the hearty support of the membership of the Association.

At the beginning of this Association year the demand for electric service, greater than at any time in history and in excess of the existing generating capacity, the difficulties of raising the necessary capital to provide for this demand and the question of a better understanding as between the industry and the public seemed to be of paramount importance. Therefore, during this administrative year a very considerable amount of attention and effort has been given to promoting this better understanding. Millions of pieces of literature have been distributed by direct mailing to member companies' customers. A national good will advertising campaign, in which all branches of the industry have co-operated magnificently, has resulted in hundreds of good will messages appearing in national popular magazines, the daily press and in trade journals. Co-operation between the Association and the Investment Bankers Association has resulted in hundreds of thousands of pamphlets dealing with the economic side of the industry being placed in the hands of bankers and investors.

Following the initiative of the Association, all branches of the industry are working together towards the end that the public may have a better understanding of their mutual inter-dependence, and the necessity of the industry being so treated that it can, without fail, give the public the service which it demands and which is so necessary in the development of the nation's business.

Constructive Suggestions by a Past President

R. H. BALLARD
Past President (1919-1920)
National Electric Light Association.

THAT we are striding rapidly along in the new era of electrical development is the predominating impression that I obtain from every point in which I come in contact with the activities of our industry. From coast to coast the awakening to the necessity of turning the output from every prime mover water, coal and oil—into electric energy has taken place. It has assumed the dignity and magnitude of a great movement of the American people for conservation of natural resources, the stimulation of a substantial prosperity, and the increase of community and national wealth.

Because the people are comprehending that there is a limit to the store of coal, oil and natural gas, their intelligence centers on economical use of what yet remains in the earth, and the conversion of these fuels into electricity is the one answer. Increasing costs of coal, oil and gas has brought the reason for these increases home to every individual consumer. The gasoline shortage was a vivid object lesson to every automobile owner.

As a substitute for the fuels of the earth, hydroelectric energy is the only possible recourse, so far as human knowledge has advanced. With this fact firmly fixed in the public mind comes a realization of the enormity of the economic crime of permitting water power to remain in undeveloped and wasteful idleness. Already the effect of the spreading interest in electric construction is manifest in the market for electric securities. Both bonds and stocks in these utilities are stronger than in other lines, and selling during a period of stagnation in larger quantities. This is entirely different from conditions a year ago, and I sincerely believe that that change is largely due to constructive educational activities of the National Electric Light Association, its geographical groups and the Central station companies of the United States and Canada.

Bringing the consumers of electricity into partnership by the purchase of junior securities insures to the bond holders, or mortgagees of the property, a higher degree of safety than they have ever enjoyed. In projects where the customer-partners are coming to own substantial holdings in the equity, the investor knows that failure and inefficiency are impossible, and this assurance will increase as consumer-ownership increases. It is quite reasonable to conclude that the number of local, or consumer-stockholders will come to be closely scrutinized, and become a determining factor in the purchase of public utility bonds and debentures by financial houses.

In presenting the advantages of becoming owners of junior securities to their consumers, central station companies can point their argument by calling attention to the "self-interest" idea, which means that, in the final distribution of the money spent for new electrical construction, not only the community, but each individual who composes it derives a direct personal profit. The accumulative value to a community, and its reflected value to each inhabitant, property owner, business man and laborer, of fifty thousand horse-power of electrical energy developed and used each year, is forcefully illustrated by a statistician, who has worked it out on the basis of the construction program of a Pacific Coast company. He finds that it will provide service to 32 250 residences, 495 factories and will provide for the irrigation of 150 000 acres of new lands. The actual expenditures for construction and development of these new enterprises will be approximately $165 000 000 for residences, $75 000 000 for factories (employing 20 000 men), and $15 000 000 for the development of the lands. The annual yield from the factories in manufactured products will amount to $100 000 000 and the production of crops from the new acreage irrigated will add $30 000 000 a year to the wealth of a community.

Summarizing the several classes of benefits, we find that 50 000 hydro-electric horse-power developed calls for a total expenditure of $45 000 000 for power plants and distributing lines, stations and equipment in resi-

dences, factories and on agricultural lands for its use. The construction of residences, factories and the development of lands will call for an additional annual expenditure of $205 000 000 and finally, the value of the manufactured products and crops produced will amount annually to $130 000 000, the grand total expenditure and yield amounting to $380 000 000 annually.

During a recent visit to the principal cities of the East and Middlewest, I had occasion to meet with the officers of the National Electric Light Association, and to discuss with them the excellent program which is being prepared for the annual convention in Chicago. It is constructive in every aspect, and will tend to broaden and widen the scope of the work, which we endeavored to inaugurate at Pasadena in May, 1920. The participation by the people in the ownership of their electric utilities is, to my mind, the most practical answer to our industrial problems. More power means more work; more work means more production, and increased production is synonymous with National prosperity.

The Utilities' Situation

MILAN R. BUMP
First Vice-President.
National Electric Light Association

THE forthcoming Convention of the National Electric Light Association at Chicago will go down in the history of the industry, I believe, as one of its greatest milestones. The work of the year, which culminates in this Convention, has been of tremendous importance to the industry as a whole. Following the aggressive plans adopted by the previous administration toward an awakening of all branches of the electrical industry to a realization of their mutual interests and interdependence, the work of this year has borne fruit in actually carrying out those steps essential to bringing about co-operation and to establishing mutual confidence between the manufacturer, the jobber, the central station and the banker.

The trials of the War period have not been without their compensating benefits. The developments of this period, particularly the efforts necessary to protect the central station industry through increases in rates, have brought about a mutual understanding between the public, the regulatory bodies and central station companies that, in my opinion, have placed the industry ten years ahead of the standing which they otherwise could have expected to have in this respect. The realization today is general, and reaches every section of the country, that the public are as vitally interested in the success of the public utilities which serve them as are the stockholders of the utilities.

When regulatory bodies were created, they first conceived that their function was to take away from the industry everything which they could claim for the public, with the idea that in this way they were serving to carry out the spirit of the acts which created the regulatory bodies. It was later realized that these same acts also contained clauses which placed a burden upon them of seeing to it that the utilities as going concerns are strong enough financially to serve the territory which they occupied properly and to render adequate service to all who demanded it. The War necessities brought this phase of the situation acutely before the public and the resultant educational effect has been tremendous.

The financial necessities of the utilities have served likewise to bring before the bankers, the manufacturing and jobbing industries the fact that they are just as vitally interested in the financial success of the utilities as they are in their own success, because it is utterly impossible for the manufacturing interests to thrive unless the public utilities are at all times in sound financial condition, and ready to take on all additional business which can be created in their territories.

The change in the policy of our Association, under which the manufacturing and jobbing interests are directly recognized in its membership, has been another means of bringing about that mutual understanding which is essential to the success of all branches of the industry.

It is believed that the forthcoming Convention will stand as the day when the realization of the mutuality of all concerned in the success of the industry can be regarded as complete, and it will be left for the coming years to develop on this basis such methods and plans as will best promote the mutual good of all concerned. Many of these plans are already under way, the greatest being, in my mind, the Good Will Campaign, in which all interests are joined with the central station industry through our Association and are building toward a firm and lasting foundation.

It has always been the claim of the public utility industry as a whole, and particularly of the electrical industry, that the securities created on going public utilities are the safest, soundest form of corporate security, and are entitled to the highest rating from an investment standpoint. The showing of stability of earnings, of growing demands for service which preclude the possibility of overbuilding, of regulation which both controls and protects, is one with which no other industry of which the writer has knowledge can compete. The conditions of the past four years have put the acid test to all of these claims, and the result has been an absolute proof that the claims are founded upon fact.

This being the case, we can look forward with great confidence to the ability of the industry to grow in the immediate future at any rate necessary to keep up with the legitimate demands for service. It is my belief that our industry will not only prosper, but that it has so many attractions that it will continue to draw to its membership the very highest type of technical and business talent, and that it will continue to be regarded as an honor to be connected with the industry and to take part in its upbuilding.

The Manufacturer and the N. E. L. A.

FRANK W SMITH
Second Vice-President,
National Electric Light Association

THE increased activities of the National Electric Light Association during the last eighteen months have crystallized the long-evident and growing spirit of co-operation between the several factors in the electrical industry, until today it is believed that the industry is united in its effort to serve the public. Through closer affiliation by representation on the executive committee and public policy committee of the Association, as well as through geographic sections and technical and other committee activities, it is expected that these relations between the different elements of the industry in which we are all so vitally interested can be cemented still closer.

The Class D and Class E membership in the National Electric Light Association, as represented by the manufacturers as Class D, or company members, and Class E, or individual members, has always been an important factor in the affairs of the Association, particularly in those activities dealing with technical and commercial matters, which have been such an important part of its work. Contractor-dealers and jobbers throughout the country are also represented in our membership, as Class F and Class G members, and it is the aim of the Association to increase this representation largely through the several classes of membership, as now provided in the constitution of the Association. Self-interest has prompted the manufacturer and jobber to participate in and support the work of the Association, just as the same self-interest has prompted the central station membership to seek that participation and support.

The purpose of the N. E. L. A. is "to advance the art and science of the production, distribution and use of electrical energy for light, heat and power for public service," and in this expressed purpose is found the basis for the interest of the manufacturer, contractor-dealer and jobber, as well as for the central station owners, officers and employes, for it cannot be gainsaid that their interest is common. All engaged in the industry have as their primary object the advancement of electricity in public service, and whether this end is attained by perfecting and manufacturing machinery, by the bettering of merchandising methods or by increasing the efficiency of distribution of electrical energy matters little—the ultimate object is the same.

The manufacturers, as represented by Class D and E members, are aiding the Association work both financially and through their personal interest and efforts as members of committees. The officials and those in close contact with the work of the Association, having in mind the plans for future development, are very hopeful of a continuation of this co-operative spirit between the several classes of membership, and are endeavoring to increase these "tie lines" until we have a complete and comprehensive "network" system for the good of the industry.

There seems to be a growing appreciation of the fact that generating and distributing machinery and equipment can have no extended market unless the electric light and power companies of the country prosper and progress in advance of general manufacturing and commercial progress, and that machinery, appliances and other equipment dependent upon electrical energy for motive power necessarily must have a restricted field unless the electric light and power companies extend their fields of service. Here is the common interest, and with this common ground upon which the various classes of membership meet, united effort is becoming more pronounced and general.

Financing is a problem in every branch of the industry which, through the co-operative efforts of the Association, we are all seeking to solve. In the central station branch of the business, financing becomes not only a problem for the entire industry to consider, but also one which can be solved best through a public understanding of the future of the industry and its relation to the civic, commercial, social and individual progress of the public. It is the issue of paramount importance at this time to the central station company and, therefore, to the entire industry.

Through its public relations section and its publicity department, the Association is endeavoring not only to do its share to bring about a better and closer understanding on the part of the public of some of the problems, but also to point the way for manufacturers, contractor-dealers and jobbers to be of assistance in aiding this movement. The details of the activities of the Association in the "good will" campaign and other publicity and advertising activities of the publicity department are well known and have been treated fully, and the executive committee and officers of the Association are appreciative of the wonderful spirit of co-operation manifested by the manufacturing members in its publicity and up-building work.

The electrical industry is a tremendous factor in the advancement of civilization, and those connected with it in any branch have more than the average opportunity for rendering service to the public. It is incumbent upon every individual connected with the industry to further its development, not only for the purely selfish benefits which undoubtedly will be derived, but that our glorious United States may continue to be the greatest electrical nation in the world, which is synonymous with the greatest nation in the world.

We are all looking forward to the future development of the Association for broader activities and, with an ever-increasing membership, a close co-operation between the different classes of this membership is essential and necessary.

The Technical Work of the National Electric Light Association

I. E. MOULTROP
Chairman, National Technical Section,
National Electric Light Association

WHILE the National Electric Light Association has always done a certain amount of engineering work, the real beginning of the existing technical organization was made when the "Committee for the Investigation of the Steam Turbine" was appointed in 1903. This consisted of three members, Messrs. W. C. L. Eglin, then Chief Engineer of the Philadelphia Electric Company, Chairman; Frederick Sargent, senior member of Sargent & Lundy, Consulting Engineers, Chicago; and A. C. Dunham, President, Hartford Electric Light Company. From this rather modest beginning the engineering work has developed to the point that today one of the four major divisions of the National Electric Light Association is devoted entirely to this work.

There are now eight general committees in the Technical National Section, comprising over 300 of the leading engineers in the utility business, and representing about 250 of the member companies who are actively engaged in engineering work of the Association. The new constitution adopted at Pasadena last year also provided for technical activities by the thirteen Geographic Divisions. Most of these Geographic Divisions have already organized their technical sections and have appointed committees corresponding to those of the Technical National Section which are interlocked and work with the national committees. In this way it is possible for almost every member company of the Association, no matter how small or where located, to be represented, take part and benefit in this technical work.

Some people have wondered why an association largely commercial should attempt so much technical work and if it could not just as well be done by the numerous existing engineering associations. If this were true, there would be no excuse for the existence of the Technical Section of the National Electric Light Association. The fact that this activity has grown from a committee of three in 1903 to its present proportions proves that there was a need for this work which was not satisfied by the existing engineering societies. The wide and growing demand for copies of reports indicates that this work is well done. By the constitutions of the several national engineering societies they cannot go into commercial matters, whereas the Technical Section of the N. E. L. A. has no such restriction. It should be pointed out that the technical work of the National Electric Light Association is not intended to and does not duplicate work which the national engineering organizations are doing. On the contrary, the Technical National Section co-operates with the various national engineering societies and in general continues the engineering work of the former, carrying its application to the utility field.

No attempt is made to create standards. The Association is a member of The American Engineering Standards Committee and its representatives will be found on practically all committees of the leading engineering societies where the work being done affects the interests of the Association. In fact, the very theory of the Technical National Section calls for the utmost co-operation with other organizations to the end that duplication of work is eliminated and all parties interested work together to the common end.

Some Thoughts in Connection with the Sale of Stock to Customers

JOHN F. GILCHRIST
Vice-President,
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FINANCIAL conditions brought about by the world war have precipitated a situation in the public utility industry which was fast approaching when the war broke out, and which would probably have become acute in the next two decades following 1914 had there been no war. The public utilities have reached a point where a normal annual growth of ten percent represents a very large amount of money in yearly income, and when this is multiplied by four or five in order to arrive at the annual capital requirements to take care of such an increase, the figure at the present time is one of striking proportions. A simple computation will indicate to the most superficial investigator what a tremendous annual sum the compounding of these increases will necessitate twenty years from now.

The conclusion which anyone will reach, who has given much thought to the matter, is that a situation is being approached rapidly in which it will be absolutely necessary to turn to the people who are being benefited by the utility service, to provide a considerable portion of the money which is essential for plant, in order that any given territory may be served. A few years ago it would probably have been thought impossible to provide the required money in this way, but a study of the comparatively small amount per customer or per inhabitant which this would amount to, and experience in developing utility company customers as stockholders, have resulted in the conclusion that this is a very practical and satisfactory method of financing, and not too difficult of accomplishment.

So common has this method become, and so general has been the experience with it, that to describe the slight variations of methods employed by different companies is not of special interest, but some thoughts may be presented the consideration of which will be profitable to those interested in this work.

In all of these stock sales, the best results have been obtained from the work of employees from all departments of the company offering the stock, who were stirred to enthusiasm by interest in and loyalty to their

company, by desire to familiarize themselves with financing methods, and by the opportunity offered to earn some extra money. However, most managements have found that, notwithstanding these inducements, it is a great problem to secure sustained interest on the part of employees so that they will work, and this condition has resulted in the employment of what might be known as "circus methods", namely, competitions and various plans to make a game of the sale. Those in charge have realized that these methods could not prevail indefinitely, and have diligently sought for other means of maintaining sales in high volume and without unreasonable cost.

An organization which may prove to be permanently satisfactory may be developed by placing in the company's territory a skeleton organization of from three or four to twenty-five or more men, according to the size of the territory, who will be paid salaries and a small commission, and who will devote all of their time to the sale of securities. These men will not only sell vigorously themselves, but will be in charge of stock sales in a limited territory. Under each of these men will be placed a number of the regular company employees, on the basis of perhaps twenty regular employees to each full time stock salesman, these employees to be selected principally on a serious agreement to work and to attend classes of instruction in stock selling, thus preparing themselves to become efficient.

This plan will not work, however, unless it is very carefully arranged, and the regular company employees who are expected to work evenings are required to take the matter very seriously, to do conscientiously a certain amount of work and to sell a certain amount of stock each week, the penalty being that unless they do, they cannot hold their position as stock salesmen.

Such an arrangement at best will probably be fairly expensive. If maximum results are desired, the writer's judgment is that "circus methods" must prevail more or less for a year or two, until a fair percentage of the company's customers have become stockholders. When, as a result of several or even many campaigns, a large number of stockholders has been acquired, it will be found that the expiration of the purchase arrangements of those who buy on time will be scattered throughout the year. Then it will undoubtedly be possible, by systematic work, for an investment department of modest size to develop a process of reselling, both to those who have bought for cash and to those who have bought on time, so that the annual sales of stock will be very considerable and will grow with the company's growth.

In all of these sales of stock it is to be hoped that figures will soon be available as to the cost of collecting installments, cost of advertising and, in fact, all of the costs of selling and getting in the money. It will thus be possible to determine in how small payments and over what periods of time it will be desirable to sell stock. When sales on this basis first began to be made, the periods covered were quite extended, but it was found that a large amount of money was paid in cash, and that those who were paying on installments frequently came in later and paid up in full.

These facts, together with an impatience to obtain the money, have prompted many of the companies to shorten their deferred payment period. There is undoubtedly much business to be obtained by adding to the plans which are now in use, a plan involving a very long period of payment. Some differential in price will have to be made in such a plan, or perhaps it may be offered only to children and young people, on the theory that they cannot pay as much as older people, and further, that they may not have the same reasons as a grown person for desiring a fairly short period of payment.

Except for the cost of handling, there is no particular reason why a plan should not be brought out to sell stock on the basis of $1.00 per share per month, added to the lighting bills. This might do even with a one hundred dollar share, but such a policy may result in the practice of issuing shares of less than $100 par value. Such a long term plan need not necessarily interfere with the sale of stock on the other basis to the same person or to some one in the same family and, so far as the writer can see, the only difference will be that it will open up a vast new field, for the person who now takes one share at $5 or $10 per month could probably be induced to take its equivalent in shares at $1.00 per month.

Another matter to which those interested in selling stock are giving thought is the question of extending the sales organizations to take in employees of manufacturers, jobbers, dealers and contractors in the electrical line. There are many reasons why these people should be included. Their interests and those of the institutions they serve are identical with the interests of the utilities; in fact, it may be said that they have a greater interest in the utilities' ability to extend than have the people employed by the utilities themselves, as the utilities could for a short time thrive abundantly without growth, whereas growing utilities are essential to the very life of the dependent businesses. Therefore, it would seem that such organizations should not only be willing that their people should assist, but should take the initiative and provide executives, not only to organize their own forces in this work, but to offer a service to the backward utilities who, because of small size, lack of initiative or appreciation of the possibilities, are not already helping themselves.

The indirect advantages to the employees are substantial. An opportunity is offered to earn in their leisure hours a large percentage of their monthly pay, a knowledge of financing and of the advantages and possibilities of saving is developed, and last and greatest, an appreciation of the size, dignity and usefulness of their industry and a spirit of co-operation is acquired, which will be of great value to the entire industry and every individual in it.

To that great division of industry which includes all of the utilities and all businesses in any way dependent upon them, there is no more pressingly important question today than that of the sale of utility securities to the public who depend on the services rendered by these utilities.

Conserving Capital and Natural Resources

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THE remarkably increasing development of large electric power systems brings up such questions as that of generating power at the source and transmitting the energy to the markets over long distance transmission lines. Even popular magazines like the *Scientific American* and the *Literary Digest* quite recently have made this development the theme of certain technical articles. A very important investigation sponsored by the U. S. Geological Survey, now well under way, contemplates ascertaining the economic features of a super power zone system for the metropolitan district of the Eastern border extending from Maine to Washington, D. C. and stretching back 150 miles from the coast. Conservation of course is the object sought, and the study will embrace all power requirements within that area, including the gradual electrification of the existing steam railroads and the bringing about of complete co-ordination of the present systems of electric power supply. To the degree that the project shows improved economies in the use of our natural resources, its promotion will be accelerated. But the amount of fresh capital required to establish such an enterprise in its entirety will probably cause progress in this direction to be made rather slowly. Undoubtedly, the comprehensive report to be expected in the early future will be highly profitable and instructive to students of central station development. Mass production and long distance transmission have been the dream of many of our pioneers in the electrical industry for years. Naturally conditions must be favorable in order to justify these ambitions. Two outstanding elements control, the nature of competing sources of power and the magnitude of the load in comparison with the distance to be transmitted. Moreover, if it is a fuel (coal or oil) conversion proposition at the source, then a point may be reached where the carrying charges on the transmission line investment, together with the line losses will exceed the cost of freight on the fuel. And these are factors which appear to be frequently overlooked in the popular conception of the problem. Obviously, there is an economical radius within which a given amount of power may be taken from a fixed station. In general terms it will require demands of over 50 000 kilowatts at high load factors to justify transmission distances of 100 miles or thereabouts. Therefore, as time goes on and there is more intensifying and concentration of load, long distance transmission will come more and more into use. Local conditions will always exert their influence and, where good fuel is scarce and costly or where large and inexpensive water power developments are assured, we will find the building of long distance lines vigorously prosecuted, as Western experience typifies. The striking feature of this issue of the JOURNAL is the emphasis given to the long stretches of transmission lines of contiguous power systems which provide valuable links in a rapidly growing cross-country power service. About fifteen percent additional mileage at the present time would close the gaps and thus achieve a continuous electrical power circuit between New York and Chicago. The through connection is not the practical attainment sought, but is merely an incident of the advantages accruing from the tying-in of adjacent systems. Maps of these systems might easily convey the impression to the lay mind that energy would be transmitted from one end of the interconnected systems to the other. Long reaches of connected transmission lines do not signify long distance delivery of power but in essence represent a closely built up industrial area in which central power is a conspicuous element.

The real merits in the tying-in of the adjacent power systems lies in economizing in the installation of spare power station capacity through the ability to draw upon the neighboring utilities in case of emergency and also in the likely improvement of operating conditions by virtue of such diversity of load as may occur between adjoining properties. Furthermore, voltage conditions and service to outlying districts, forming the points of contact between two systems, are thus evidently bettered. Owing to the pressure which has been applied to the central station industry by the increasing power demands, together with the recently restricted flow of new capital, most facilities of the utility companies have been lately worked to the limit. Hence, sudden emergencies necessarily compel very prompt action. As a practical case of the advantage of interlocking systems, we might refer to the three large independent systems operating throughout Western Pennsylvania, Eastern Ohio and the Pan Handle of West Virginia, which are tied in at several points. A hurried call, say, for 10 000 kilowatts from one company at Pittsburgh may only be satisfied at the particular time by rushing certain reserves of the second company into service at Canton, Ohio, and making virtual delivery over lines of the third company forming the connecting link, and the reverse or a different combination of circumstances may obtain. What actually takes place in accomplishing these results is a redistribution of the loads on the various power stations affected. There have been at times as much assistance as 45 000 kilowatts temporarily given by one company to the other. The U. S. Government, during the latter stages of the world war, was very active through the Power Section of the War Industries Board in the planning of tying-in of neighboring power systems and particularly those that were serv-

ing munition and other war supply establishments. The large question in this particular development centers about the harmonious co-ordination of the systems to be linked together, so that the greatest good will result, with complete equity obtained between all interested parties. Impartial analyses will point the way. In the East, committees have been appointed with just such objects in view and certain adjoining companies already have quite successfully formulated and made effective co-operative working arrangements. Thus, we have seen the trail blazed and may, therefore, expect succeeding years to bear abundant evidence of activity in this direction. No doubt even broader economic policies will follow.

The Use of Central Station Power by Industrial Plants

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THE use of electric drive in industrial plants has increased at a phenomenal rate during the last ten years. The percentage of electric horse-power to total primary horse-power is now about 55 percent, which is more than double what it was in 1911. On the basis of a normal growth of industries during the next five years, it seems reasonable to predict that by 1926 industrial plants will be 70 percent electrified.

Central station power has been one of the main factors in assisting the electrification of many plants, particularly those of small capacity. The extent to which central station power is available will be an important point in the future electrification of industries and will largely influence the percentage of electrification as existing within a period of five years.

The industrial plant load is doing much to fill in what has been a low load period of the central stations and also has improved the load factor. A few years ago at least 75 percent of the electric energy generated by the central station was used for lighting and street railway purposes. At present, however the power load predominates and in many cases ranges from 55 to 65 percent of the total. This is very encouraging to the central station companies, and they feel confident regarding their future growth as far as the question of demand is concerned. From the power user's standpoint, this will depend largely, on the rehabilitation of industrial plants which are using drives that are inadequate and in a badly worn condition, and later additional load will be obtained by the growth of the industry.

From the standpoint of economy the small industrial plant cannot compete with the central station in cost of power, and with the price of coal as established during the last few years, there are not many large plants that can generate power as cheaply as the central station. It is a well-conceded point today that, with the central station power at even somewhat higher cost than that of the private plant, it is advisable to consider its use. Its advantages are of a broad character, reducing first cost of investment in the plant, eliminating supervision of an important operating item, permitting more attention to the direct processes of manufacturing, and giving a definite basis for distributing and analyzing power costs.

Regardless of what might have been the situation in the past, the central station today is developed to give reliable service. The details of plant construction, the question of spare units, the distributing system and, in most districts, the tie-in circuit system, give assurance of continuity of service. The question of rates is not so much of a problem, because practically all indefinite features from the standpoint of both the central station and the customer are being eliminated. Central station power load has now become a reality and experience gives the power companies a substantial basis for estimating costs and enables them to establish rate schedules on a basis consistent with the various demand conditions. Much data is available regarding the load requirements of different classes of industrial plants. These conditions tend to a more definite contract and should do much to encourage the use of central station power by the larger industrial companies.

Economy of operation is the watchword of industry, particularly at this period. Every industrial plant should have its production costs definitely established and, where the plant generates its own power, a close analysis of this element of cost should be made. The price of coal has advanced as much as 300 percent in some districts and labor is practically double what it was a few years ago. It will be found that the central station rates on an average have not increased proportionally during the last several years, and the change is quite in contrast with the cost of power as produced by private plants. This is made possible by the expansion of the central station and by the better load factor conditions. More economical sizes of generator units installed, and more economical station layouts, with improved designs of boilers, distributing systems, etc., have assisted in reducing generating costs almost enough to make up for the increased cost of coal and labor.

Further improvement in the central station will come with its continued growth; it is, therefore, something more than a selfish interest on the part of the industrial plant owner, when he considers the use of central station power to better his own plant conditions and costs. He is thinking of the community interests and what it means to the public to have improved power service, including greater assurance of continuity of service and reduced cost, all of which are made possible only by the opportunity given the central station to grow. The central stations need the support of the industrial companies and engineers and in return have much to give.

The Pittsburgh Power Zone

A. H. McINTIRE

As a means of aiding in the work of the National Electric Light Association, it has been the custom of the Journal to publish a convention issue about the time of the annual meeting of the Association including discussions of the subjects of most vital interest to central station operating men at the time. The present issue contains numerous contributions of this nature from some of the most prominent engineers in the central station industry, including five of the executive officers of the National Electric Light Association.

Each year particular attention has been given to some recent central station developments which seemed most important at the time. For 1921, it was found that the greatest central station development has been in the Pittsburgh district, where two super power plants, each designed for an ultimate generating capacity of 300 000 kilowatts, are being placed in regular service, with accompanying extensive increases in transmission lines and substations. Accordingly, arrangements were made with the executives of these central station companies for full descriptions of these installations by the engineers who had originated and supervised their construction, and these two groups of articles appear in the present issue of the Journal, along with other articles on subjects of broad general engineering interest.

Each of these new power plants is located on a river affording sufficient condensing water for a 300 000 kilowatt installation. In addition they are examples of the mouth-of-mine type of station, as each is located adjoining large coal fields controlled by the power companies. Such locations are desirable from two view points. They eliminate the necessity of paying a profit to coal mining and transportation companies, and afford added insurance of continuity of service, as there is no possibility of interruption of the fuel supply, due to strikes or other difficulties on the regular transportation lines. There is also, as pointed out by Mr. Bell in this issue, the further possibility of increased economy due to the continuous use of a uniform grade of fuel whose characteristics can be thoroughly analyzed by the operating forces; whereas with purchased coal it is necessary to make use of whatever fuel the railway or water transportation companies are able to deliver.

The central station industry as a whole is vitally interested in the development of these mouth-of-mine super-power plants with their transmission systems and methods of interconnection, as discussed in detail by the officials of the Duquesne Light Company and the West Penn Power Company, as they represent a definite effort to incorporate the most advanced present-day practice in power plant design. At the same time the new plants at Colfax and Springdale are essentially different in many details and doubtless much valuable data will be obtainable by comparing the operation of two such plants, both using the water from the same river and coal from nearby veins.

In the territory between Boston and Washington the government has been making a survey of the power situation and possible improvements therein. This analysis, which is soon to be completed, will doubtless be of great importance as a forerunner of similar studies in other districts. Many of the present Boston-Washington power plants are located at sea level, where abundant condensing water is available, but the fuel must be transported considerable distances. Coming westward from this seaboard super-power zone, there is another district which presents corresponding although different problems. In the Pittsburgh power district, where an interconnected system has already begun to develop, there are still further possibilities in the way of increased economies, both of generation and construction, as exemplified by the two immense power plants now being placed in service. Roughly, the present limits of the Pittsburgh power zone, based on transmission lines already in existence, extend from East of Altoona, Pennsylvania to about the middle of Ohio, and includes the various systems beginning with the Penn Central and Penn Public Service on the East and extending to the American Gas & Electric and the Doherty properties in Ohio. In some cases numerous interconnections already exist; in others, there is actual crossing of lines; in others only short gaps need to be bridged. Part of this power is being transmitted at 132 000 volts, and over 100 miles of other tower lines have been constructed for ultimate operation at this voltage, with 132 000 volt transformers and circuit breakers already installed.

An idea of the territory included in this zone can be obtained by reference to the first illustration in the article by Mr. Humphrey in this issue of the Journal. In this territory are four new mouth-of-mine super-power plants Seward, Springdale, Colfax and Windsor—the last named being the only one to get into service before the end of the war, although Springdale was begun under government supervision. The Colfax and Springdale plants have been carrying load for some months and the Seward plant is about ready for regular operation.

On account of the enormous amount of war orders placed in the Pittsburgh district at the beginning of the war, the then available generating equipment eventually became so overloaded that the Power Section of the War Industries Board was placed in charge of the situation to avoid confusion and delay in the production of essential war materials. A thorough investigation was made of the facilities of the various utilities and the possibilities of securing a greater diversity factor by interchange of loads. A few weeks ago, the War Department published a limited edition report on "The Power Situation during the War", which included an analysis of the power situation in the Pitts-

burgh district. From this report, it appears that the public service companies of this district alone have an installed generating capacity of considerably over 1 000 000 kilowatts. In addition to this, the report shows an estimated present generating capacity in isolated power plants of over 700 000 kilowatts, in addition to about 800 000 kilowatts in the major steel companies, or a total of considerably over two and one-half million kilowatts as the generating equipment of the entire district.

In the steel industry a considerable amount of power is being generated by the utilization of waste heat and blast furnace gas, which, for the present at least, as pointed out by Mr. S. S. Wales in this issue, can hardly be superseded by central station service. However, many rolling mills, wire and rod mills, tube mills, ferro-alloy electric furnaces, etc., do not have the benefit of cheap power from blast furnace gas, and government estimates state that about half the power used by the steel companies in the Pittsburgh district is produced from coal burned under boilers. This power can be considered as prospective central station business.

As indicated in the articles by Messrs. McKinley and Gadsby, the Pittsburgh power district is the largest and most congested industrial district in the United States and a sufficiency of dependable power is a vital necessity to the continued development of the district. In addition to the new industries which are continually being started, the normal growth of the manufacturing establishments already operating will provide large increases in load. This is especially true of those industries in which heat treatment of steel or other materials is an essential part, as the use of electric furnaces and electric ovens in a wide variety of forms is increasing at a phenomenal rate.

The coal mining industry is an important power user in the Pittsburgh district. Notwithstanding the fact that the coal companies have fuel immediately available, the power companies are becoming quite successful in arranging to supply their service. Thus the coal mine load is one of the large items in the list of industries which the power companies serve.

The Government investigation revealed that the load of the various power systems in the Pittsburgh district has been increasing at the average annual rate of 13 to 15 percent compounded annually or, in other words, it doubles every five years. As a part of the government power survey an estimate was also prepared as to the probable power requirements of the district for the year 1926. This indicates a probable need for generating capacity around one and one-half million kilowatts, without including steel mills or the possible electrification of existing steam railroads. Government estimates show that steam railroad electrification for the district would involve the installation of at least 500 000 kilowatts in generating capacity. As to the steel mill load, this is a matter that will have to be worked out with time and is complicated by the general use of 25 cycle equipment in most of the mills. There is an increasing tendency to make use of central station service and undoubtedly a large load will ultimately accrue to the utilities from this source.

While the Pittsburgh district is blessed with immense coal fields, there are also a number of water power resources, some of which have already been investigated. It is to be hoped that, as a means of coal conservation, some feasible method can be worked out for the development of all commercially practicable water powers. Naturally, in a commercial corporation, pure economics control and it is hardly reasonable to expect power companies to develop water powers unless such developments show a possibility of a cost of operation, including interest on the investment in dam, power plant and transmission line, on at least an approximate parity with the cost of generating power from coal. This subject is discussed in detail in this issue by Mr. Mead. Of course, from the national conservation standpoint, water power development is of primary importance and the study of some means of securing such development as promptly as possible should command the attention of our leading legislators and public spirited citizens, as every year's delay means further depletion of a non-renewable coal supply. Certainly some broad-gage national plan should be formulated by which this whole problem can be thoroughly studied and developed into a workable basis of action which will result in true conservation.

An 80-Mile Central Station Bus

C. S. COOK
General Manager,
Duquesne Light Company

IN THE Colfax station of the Duquesne Light Company three cardinal points of station design have been kept closely in mind—simplicity, economy and reliability. The greatest of the three is, of course, reliability for on that characteristic depends to the maximum extent the Company's ability to obtain and hold load from the power users and industries in the district. Reliability is, of course, very closely allied to simplicity as, in general, the simpler any mechanical or engineering development the more certain and reliable is its operation.

In economy it is necessary to consider both the economy of operation—fuel, labor and incidental supplies, and also the economy of investment costs—overhead, to the end that the sum of the two may be a minimum, as overhead cost is no less real than the direct cost of operation.

This power house is extremely fortunate in its location. It is truly a "mouth-of-the-mine" plant of the type we have heard so much about and seen so little. The prime requisite of such a power plant is water, and there are but few localities outside of the Pittsburgh district where a large power plant can be located at the

mouth of a mine and, at the same time, on the bank of a large body of water such as a lake or a river adequate to supply the cooling medium for a station capacity of 300 000 kilowatts or more.

The bringing of this power to the industries in the Pittsburgh district has been worked out in a way making for the maximum of reliability. Practically a 66 000 volt bus system surrounds the entire district, sectionalized as though it were employed in the standard central station of modern design. Eventually, and with the installation of additional units, this plan will be more apparent than it is at the present time, as the different units in the Colfax power plant will feed into this 66 000 volt bus system in different sections, connection being made in the high-tension substations located along this bus or, as it has been termed, "ring feed". This method goes still further to ensure service, as it protects the system as a whole against the terrific effects of short-circuits that might exist were a plant of the contemplated eventual size of this installation operated directly in parallel in the power house and through the regular power house switching gear. 22 000 volt through connections with appropriate relays will also be used between various of the substations on this main line, which further tends to ensure continuity of service for the industries supplied therefrom.

The ring feed system of itself is to a large measure an actual demonstration of the super power idea. Arrangements have already been made with various other utilities around the Pittsburgh district for interconnection with this ring feed for the interchange of energy and mutual support in the service of the interconnected companies, and it is only a question of time until still further interconnections will be made.

It requires no great stretch of the imagination to foresee the day when such interconnection between adjacent utilities will become general and the industrial sections of the country covered with an interconnected high-tension distributing system which will furnish an abundance of reliable and cheap power to the industries requiring it. The economic value of such a system is manifest further in that it will render available, for industrial and manufacturing purposes, sections where today the want of adequate water supply for power purposes or where the want of a readily obtainable fuel supply makes such industries impossible.

The Central Station Company as a Community Asset

A. M. LYNN
President,
West Penn Power Company

IN THIS issue of the JOURNAL are two groups of articles describing the central station power service supply of the Pittsburgh district. The transmission lines as shown on the maps accompanying these articles afford a density picture of the industrial development of the territory supplied. In other words, where the lines and substations appear in greatest number, there also will be found the largest number of factories, mines and industrial operations.

During the past twenty years the central station has definitely placed itself in the economic life of our industrial centers. It has taken a part of that time for the central station company to reach that degree of efficiency which places it among the determining factors of industrial life and growth. It can now be safely stated that the central station has caught up with industrial activity and, at least in the Pittsburgh district, power lines are to be found wherever there is any marked industrial activity.

In point of availability of service the developed area is approaching the point of saturation. From now on the central station will be one of the major agencies for new developments. This applies not only in the working out of new processes, but in the location and settlement of new factory sites and locations of towns and cities. The ability to deliver power across great expanses of country without regard to topographical conditions has opened up areas which heretofore have been suitable for agricultural purposes only, and sometimes not even suited for farming. Today the factory location may be determined by available transportation facilities, electric supply, and proximity of raw products and markets for the finished product. The great problems heretofore attendant upon the production of power have been eliminated and the manufacturing plant, which had to consider fuel and water supplies and ash disposal in picking its location, may now be moved to the heart of the city or to the site in the open country best adapted for the construction of the factory and the homes of the workers.

Community bodies, such as Chambers of Commerce and Boards of Trade, are just commencing to realize the value of power service in advertising their cities and towns. It will not be long before the claim to an adequate power supply will supersede the claims of transportation, climatic conditions, pure water and beautiful scenery, which have heretofore been featured in the prospectus sent out to attract manufacturers to the community.

From the community point of view this carries a responsibility as well as an advantage. The product of the central station is entirely for home consumption. It cannot pack its kilowatt hours and ship them outside of the territory it serves. It is reasonable to expect, therefore, that the financing of the central station company must, in increasing measure, be provided for by its patrons and those interested in the growth of the district in which it is located. The response to this need is being experienced by central stations in all parts of the country and a comparison of the number of local shareholders from year to year will reflect the appreciation on the part of the local public of the value of the central station.

During the past two years there have been a num-

ber of outlying towns in the territory of the West Penn Power Company which have entirely financed the construction of power lines into their communities, the subscription to the necessary securities being handled by the local bankers, leading merchants and public spirited citizens. In most cases those who have been most active in this work, taking securities themselves and soliciting the purchase on the part of others in the town, have not been manufacturers or prospective power users, but the work has been done as a far-seeing public-spirited movement for the development of the community, with the sure knowledge that the availability of the power supply will result in the growth of the town and resultant gain to all of the business interests therein. The outcome of this action has not caused regret on the part of the local people who have interested themselves in it.

The desirability and economy of central station service need no longer be preached with the insistence which has been necessary heretofore, but the true value of this service as an asset to the community may not always be realized and the central station interests, in emphasizing this feature, will be performing a service not only to themselves but to the welfare of the communities. A good text for publicity work may, therefore, be; "Central Station Service—a Community Asset".

Now for the N. E. L. A. Convention

E. H. SNIFFIN
Manager, Power Dept.,
Westinghouse Electric & Mfg. Co.,

THE Convention meets again. Old friends foregather with the mutual respect and high spirit of men who have done big things. Most of the faces are familiar, with a new one here and there that we gladly welcome, for this virile industry invites new blood and new strength to help with the work that lies ahead.

An animated scene, this gathering of N. E. L. A. men. Walk among them and the striking impression is one of vitality and purpose. Strong, work-lined faces, set to earnest thinking, but breaking easily to hearty laughter until you wonder which they enjoy the more, work or fun. For we all know that a man's happiness is not measured by his smile, and it is in the genius of American business that we take our fun as we go along, even out of the business itself. The blue bird is not found in the pleasure resorts. He perches right where we live and work and do things and serve. Our Puritan fathers made of their work an article of religious faith and a stern duty with no attributes of fun or enjoyment. That was a necessary condition of clearing the land, fighting the Indians and establishing civilization. We still hold to their conception of work and service as a duty, as the basis of our National life, and as an honorable requirement of all men, but we have learned how to enjoy it and to put some humor into it. And we are gradually learning how to play a little and keep our minds and bodies in efficient condition so that each of us may produce the maximum results in a life-time. We are accused by the older countries of a rawness which they do not relish, of being below their standards of culture in literature, in art, in philosophy, in our general outlook upon life. Perhaps that is true, but their culture has not spared them from their present social and economic upheaval and it has not given to their national morality very much that we would aspire to. We all covet education. In an elementary way we are spreading it more generally than is any other country. And it is a fine thing to be highly educated, widely versed in literature, art, history, to know how people of all ages have lived and thought: to be familiar with the conditions, causes and results that have influenced all human affairs. It would be better if some of our ills were removed by a sound philosophy rather than attempt it by legislation.

But we don't want the culture that breeds caste and indolence, that puts the stamp of privilege or restraint upon any birth. We don't want the culture that takes the place of performance, that flaunts the profession of gentleman. We say of education that it obligates the man who gets it, to use it, and we think of culture as a refinement of mind that expands our interest and curiosity into new fields of enjoyment and probably of usefulness. Solomon said "In much wisdom is much grief, and he that increaseth knowledge increaseth sorrow". That was the lament of an old man satiated with the pleasures of life whose philosophy was wrong because he failed to use his rare gifts. Most of his wisdom was written down after he had been a fool. He admits it.

Let culture come to us, slowly, if need be, and it will come in its good time. We have not had much time for the humanities, for contemplation and polite thought. There has been too much work to do. But while sometimes conscious of our narrow limits, let us not forget that we have built up a Nation, that we have enriched the world with our inventions, our enterprise and our toil, that we stand before the world today as the only great Nation whose ideals are scoffed at in the Courts of sophistication and culture, but which are emblazoned across the skies where all weak Nations look up to the stars. In our Puritan atmosphere may still be many faults, but we have reared successive generations of men who have stamped upon our national character the gospel of industry, which in turn has been the pabulum of a high public morality. Let our culture grow in that good soil.

The Transmission System of the West Penn Power Company

GEO. S. HUMPHREY
Electrical Engineer,
West Penn Power Company

THE West Penn Power Company and affiliated companies have charters for approximately 4800 square miles of territory in Southwestern Pennsylvania and 200 square miles in the Panhandle District of West Virginia. This territory has an extreme width, east and west, of 75 miles and an extreme length, north and south, of 100 miles. Approximately one-half of this territory is thoroughly covered by transmission lines, so that any new load may be reached by constructing only a comparatively short line. Lines are being extended into sections which are not now served, as rapidly as required by industrial developments. The load center is 4.5 miles west and slightly north of Elizabeth, Pa.

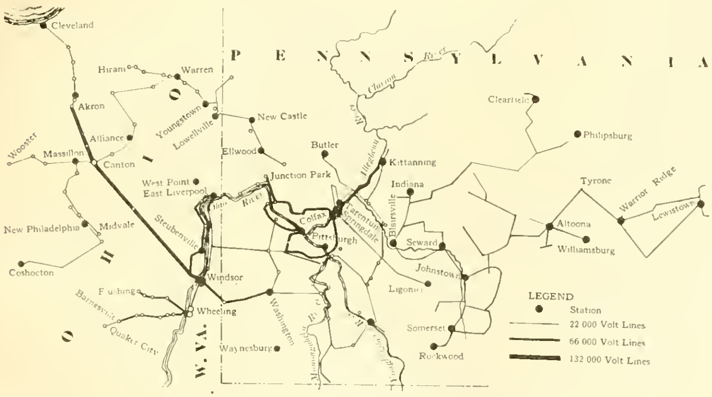

FIG. 1—POWER GENERATING AND TRANSMISSION SYSTEMS IN WESTERN PENNSYLVANIA AND EASTERN OHIO

The load is distributed over a network of lines, which, on December 31, 1920, contained 855 miles of 25 000 volt circuit, from which power is taken through 180 substations, which reduce the voltage from 25 000 to 6600 or 2300 volts for use by a single customer, or for further distribution at lower voltages, as may be required. The 25 000 volt network receives power at four main points:—

1—Connellsville Power Station
2—Springdale Power Station
3—Windsor Power Station
4—Washington Substation

There are in addition seven small power stations which may feed power into the net-work, and which are used when, for any reason, the other stations are unable to carry the load. This network is also connected to interchange power with the Duquesne Light Company at nine different points, the principal ones being the Cheswick, Elizabeth, Washington, Canonsburg, McDonald and Bridgeville substations. Connection is also made at Windsor and East Liverpool with the system of the American Gas & Electric Company, which in turn is interconnected with the Akron properties of the Northern Ohio Traction & Light Company. It has been found that the interconnection of the transmission lines of the various companies has been of considerable mutual benefit, especially in cases of emergency.

All of the transmission lines at present are operated at 25 000 volts except the steel tower line from Windsor power station to Washington substation which is built and insulated to operate at 132 000 volts, but has thus far been operated at 66 000 volts. There is another steel tower line, constructed and insulated to operate at 132 000 volts, from the Springdale power station to Crows Nest substation, but this line is at present operated at 25 000 volts. Until 1917, when the Windsor-Washington 66 000 volt line was put in service, the entire load, then amounting to 60 000 kilowatts, was transmitted at 25 000 volts, and a comparatively large amount of power is still transmitted at this voltage. It is possible to give satisfactory service with this voltage, since the load is transmitted from power stations in several different directions, good power-factor is maintained by the use of synchronous apparatus, and automatic induction voltage regulators are used on all lighting circuits and most important power circuits. It has been the practice to build 25 000 volt lines rather than higher voltage lines wherever practicable, since load may be taken more economically from the lower voltage lines. It is intended to raise the voltage on the existing steel tower lines, and to extend the 132 000 volt lines as may be necessary to supply additional service as required. The probable location for such lines is shown in Fig. 2, although future industrial developments may make advisable some changes in these plans.

The oldest of the three main generating stations is at Connellsville. All of the 25 000 volt apparatus at this plant is indoors and each of the main generating units has its own bank of transformers, which are paralleled only on the high-tension side. The 25 000

volt electrically controlled circuit breakers are mounted in concrete cells. The 25 000 volt busses are also mounted in cells. Each line is protected against lightning by electrolytic lightning arresters and choke coils. There are five banks of transformers having a total capacity of 61 500 kv-a, which raise the voltage from 2300

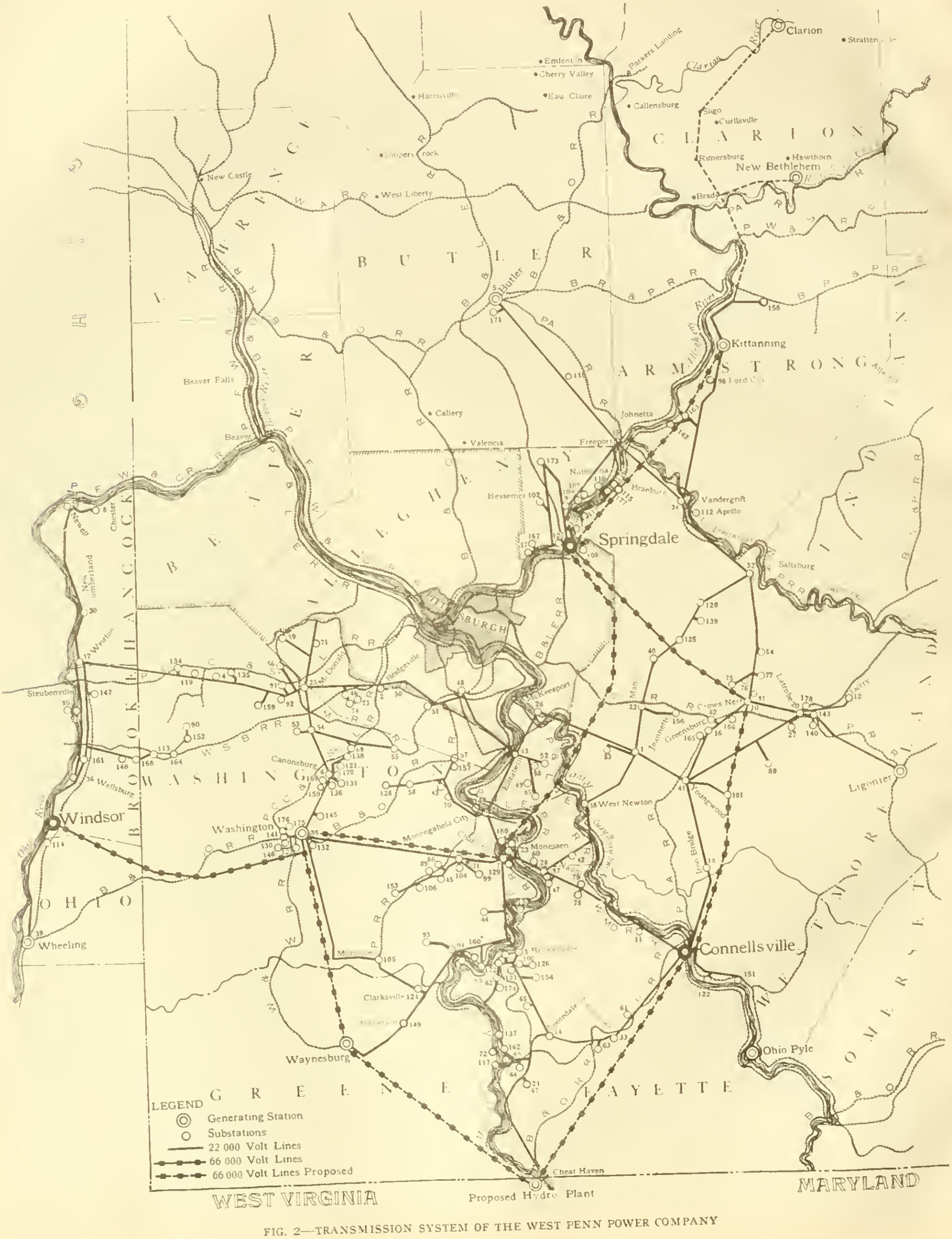

FIG. 2—TRANSMISSION SYSTEM OF THE WEST PENN POWER COMPANY

volts delta to 25 000 volts delta for three 7500 kv-a banks, and to 25 000 volts star with neutral grounded through resistance for two 19 500 kv-a banks.

At Windsor, the next station put in service, all of the high-tension equipment, both 132 000 and 25 000 volts, is outdoors. There is a bank of three 10 000 kv-a transformers, with a fourth as spare, which steps up the generator voltage from 11 000 volts delta to 66 000 volts star, with neutral grounded without resistance. The transformers are protected by circuit breakers, electrolytic lightning arresters and choke coils. All of the apparatus is built to operate at 132 000 volts although now used at 66 000 volts. There is at present a bank of three 3500 kv-a transformers which step up from generator voltage 11 000 delta to 25 000 delta. A new bank consisting of three 6667 kv-a transformers, with a spare, is being installed to supply the 25 000 volt lines in parallel with the present bank of transformers. The new bank will be connected star on both sides and have a tertiary delta-connected winding to hold the neutral point stable and supply some 2300 volt service. The star connection is being used so that the 25 000 volt neutral may be grounded as at the other generating stations. Since the existing bank is connected delta on both sides the new bank must be connected star on both sides so that the two banks may operate in parallel. The Windsor station will then have a capacity of 30 000 kv-a at 66 000 volts and 30 500 kv-a at 25 000 volts. At present three 25 000 volt lines are supplied from this station and two more will be added in the near future. Lightning protection consists of electrolytic arresters and choke coils on each circuit.

FIG. 3—DEAD-END TOWER ON THE SPRINGDALE-CROWS NEST TRANSMISSION LINE

This line is insulated for 132 000 volts but is now operated at 25 000 volts. It carries two No. 4/0 copper transmission circuits, two 3/8 in. copper clad overhead ground wires and two No. 8 phono-electric telephone wires. The line is graded to allow the addition of one 25 000 volt circuit.

At the Springdale power station, which was put in service in 1920, there are two banks of transformers, each consisting of three 8333 kv-a transformers, with a seventh as spare, which supply the 25 000 volt network. These transformers are connected 11 000 volts delta to 25 000 volts star with neutral grounded through resistance. The transformers are installed outdoors and the electrolytic lightning arresters are placed on the turbine room roof. The rest of the 25 000 volt equipment, including busses, circuit breakers, instrument transformers, etc., is placed in doors. It was originally intended to place all high-tension equipment outdoors on an elevated concrete platform. This platform would have to be about twenty feet above ground level to be out of reach of floods and be supported on piles driven 15 feet to gravel. Since there was space on the main switch floor which could be used, it was decided to place the 25 000 volt switches and bus in doors.

The top conductors of the four circuits crossing the Allegheny River must be supported at a distance of 175 feet above the ground, and since the building columns have ample strength to support these circuits, the supporting tower for the river crossing and the lightning arresters are placed on the roof. A considerable saving in

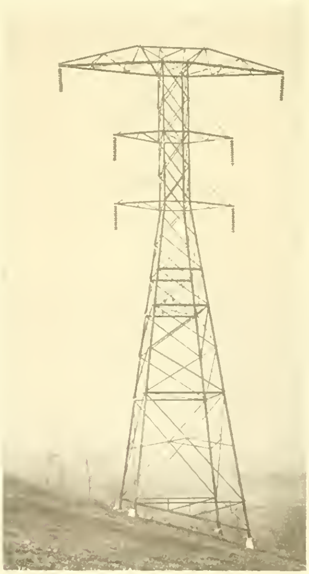

FIG. 4—TRANSPOSITION TOWER ON THE WINDSOR-WASHINGTON TRANSMISSION LINE

Showing a standard tower in the distance. This particular tower is located on a short section of the line where, to secure the right of way, it was necessary to install at the beginning all the conductors that would ever be placed on the tower. A special long cross-arm is provided to facilitate making the transposition. To avoid excess grading on hillsides, extensions in multiple of 2.5 ft. are added to the base of the standard tower.

structural steel as well as in concrete was thus realized by placing most of the high-tension equipment in the building and on the roof. Since there was room in the building to give the equipment and conductors practically the same spacing they would have had outdoors, and in addition to install barriers, it was considered that the reliability would be considerably greater indoors than outdoors. The 25 000 volt busses are arranged vertically in concrete cells. Each 25 000 volt circuit breaker is mounted in a separate room 10 by 12 by 25 feet high, and is electrically operated. Each 25 000 volt line is equipped with a grounding device, consisting of three knife switches mounted on top of the bus structure and controlled from a single handle mounted in the corresponding switch-room. The grounding device is electrically locked in the open position, when the line is alive, by means of current supplied by a 25 000 volt potential transformer connected on the line side of the circuit breaker. When the handle is in the closed position, it opens the closing circuit for the corresponding circuit breaker. Thus it is impossible to ground the line unless the circuit breaker is open, and it is impossible to close the circuit breaker when the line is grounded. Springdale can thus supply 50 000 kv-a to the 25 000 volt lines. It is probable that this is all of the power that can economically be transmitted from the station at this voltage and that the power from future units will be transmitted at 66 000 or 132 000 volts.

The Washington substation contains two transformer banks, each with three 5000 kv-a transformers, with a seventh unit as spare, which reduce the voltage from 66 000 delta to 25 000 star, with neutral grounded through resistance. All of the 132 000 volt apparatus is installed out doors and the apparatus and installation are practically duplicates of the similar installation at Windsor. The 25 000 volt apparatus is installed indoors, as there was available a brick building in good condition which had been used as a steam plant. The 25 000 volt circuit breakers are mounted in cells and each line is protected by low equivalent lightning arresters.

The Windsor-Washington steel tower line is 26 miles long and carries one circuit of 4/0 stranded copper wire, two 3/8 in. galvanized steel overhead ground wires and two No. 8 phono-electric telephone wires. Space is provided for an additional 132 000 volt circuit and a 25 000 volt circuit may also be added. There are four types of tower on this line, each of which is used in two standard heights; a 40 ft. tower, which carries the lowest 132 000 volt conductor at a distance of 40 ft. above ground, and is 76 ft. 9 in. high, and a 50 ft. tower which is 86 ft. 9 in. high and gives a minimum wire distance of 50 ft. above ground. The weights of the towers are as follows:—

Type	Used For	Weight of Tower 40 Ft.	50 Ft.
S-1	Suspension	7600 lb.	8500 lb.
S-2	Suspension	10100 lb.	11200 lb.
A-1	Angle	10700 lb.	11800 lb.
D-E	Dead End	10900 lb.	12000 lb.

The *S-1* tower is used only on straight line sections where spans are not over 550 feet and the *S-2* tower on straight line sections for spans between 550 and 800 ft. The *A-1* type is used at points where there is a horizontal angle or where the spans are more than 800 ft. The *D-E* tower is used wherever wires are attached by strain insulators. The longest span on this line is 1150 ft., the shortest is 265 ft. and the average is 564 ft. The footings for all types of tower consist of angles set in concrete to a depth of 7 to 8 ft. in the ground. On hillsides, extensions in multiples of 2.5 ft. are added to the base of the tower on one, two or three legs as required to avoid excessive grading. The tower proper is connected to the footing angles by means of an angle about 2.5 ft. in length, which is half imbedded in the concrete footing where the steel leaves the concrete. This short piece should show the most rapid deterioration and can be replaced without interrupting service or injuring the tower. Insulators of the suspension disk type are used, eleven in series at suspension points and two strings of twelve disks each in parallel at strain points. Each telephone wire is supported on two 25 000 volt pin insulators at each tower and is transposed at each tower. The power circuit has two transpositions which divide the entire length into three equal portions. The horizontal spacing between conductors is 29 ft. on the middle crossarm, and 22 ft. on the top and bottom arms. The vertical distance between crossarms is 13 ft. Since this line will transmit satisfactorily at 66 000 volts, all the power that will be needed from Windsor to Washington until additional units are installed at Windsor, or until the 132 000 volt lines are extended beyond Washington, it has been operated at 66 000 volts with insulation for 132 000 volts. In the four years this line has been in service it has had but two interruptions, both from external causes.

The steel tower line from Springdale to Crows Nest has towers which are duplicates of those on the Windsor-Washington line. However, the Springdale-Crows Nest line carries two No. 4/0 copper circuits insulated for 132 000 volts, but now operated at 25 000 volts; two 3/8 inch 40 percent conductivity copper-clad overhead ground wires, and two No. 8 phono-electric telephone wires. On this line nine Jeffrey Dewitt disks are used at suspension points and two strings of ten disks each in parallel at strain points. The longest span on this line is 1450 ft. where it crosses the Allegheny River at Springdale, one end of this span being supported on a 75 ft. tower on top of the turbine room and the other end on a twin tower 145 ft. high. The longest span, using standard towers, is 1288 ft., the shortest span is 250 ft. and the average is 625 ft. This line was completed in September, 1920.

The 25 000 volt lines form a rather complicated network, containing many loops and cross-connections, so that it is possible to supply most consumers from more than one direction. There are approximately 560 miles of 25 000 volt wood pole line of which 250 miles

is double circuit and short sections in congested districts carry as many as four circuits. Standard construction uses 35 ft. chestnut poles with an average spacing of 132 ft., locust pins, Douglas fir cross-arms and braces, and steel channel extensions with insulating spool for supporting the overhead ground wire. Pin type insula-

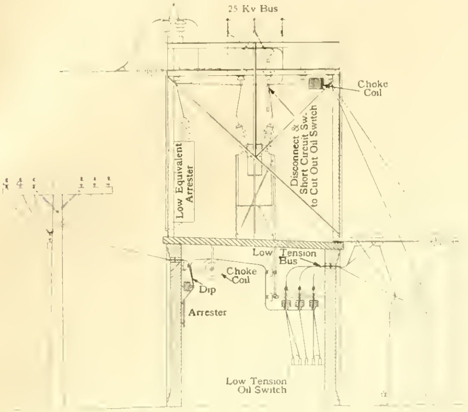

FIG. 5—A TYPICAL MEDIUM CAPACITY 25 000 VOLT SUBSTATION

With 25 000 volt apparatus outdoors, and low-tension switches, induction regulators and other apparatus located in a small brick building.

tors are used which are rated at 35 000 volts and they, together with the wooden pins, cross-arms and poles, make very effective insulation for 25 000 volt lines.

The first of these lines was built in 1903 and no overhead ground wires were used until 1910. At that time an overhead wire was installed on a few sections of line to determine whether or not the troubles from lightning would be decreased. The improvement was so apparent that ground wires have been added to all 25 000 volt lines and have for several years been standard construction. The ground wire was added to existing lines by supporting it on angle extensions bolted to the tops of the poles. The first overhead wires installed were clamped directly to the supports, but from an experiment made on a section with ground wire insulated, it was thought to be of some benefit to have a little insulation between the ground wire and support. The present standard practice is to attach the ground wire to an insulating spool by means of tie wire, the spool being bolted between the flanges of a four inch channel which has the web cut out to make room for the spool. This provides a very good mechanical connection and eases off vibrations of the wire at the support. No. 4 solid copper wire is used for overhead ground wire, and it is grounded every fifth pole. Two of the eight grounds per mile are made to Paragon ground cones and the remainder to pipes driven eight feet in the ground, using one cone or one pipe for each ground. A ground is always installed on a pole near a stream. Most of the 25 000 volt circuits are of 1/0 copper wire; however, a few of the main sections are of 4/0 copper, and short branch lines are of No. 4 copper. The spacing between conductors is 36 inches with the three conductors of each circuit, of a double circuit line, in the form of an equilateral triangle.

Standard construction is used for crossings over railroads or communication circuits except under unusual conditions. A large part of the 25 000 volt poles carry low-tension distribution circuits and space is always allowed for at least one such circuit. A private telephone circuit is carried on all pole lines except short branch lines to the less important loads. The telephone circuit is of No. 10 copper wire attached about seven feet below the 25 000 volt conductors and is transposed every five poles.

The one hundred and eighty 25 000 volt substations cover a wide range, the largest having a capacity of 9750 kv-a and the smallest 150 kv-a. Some of them have switching equipment to control several 25 000 volt lines, motor-generator sets or rotary converters to supply railway or mine load, synchronous condensers for voltage control, and a number of low voltage distribution circuits at 6600 or 2300 volts or both. Many of the substations are very simple, consisting only of 25 000 volt lightning arresters, air break switch, fuses and transformers, all of which are placed out doors. The West Penn Railways Company, which is affiliated with the West Penn Power Company, operates street railways over a large part of the territory served by the Power Company, and it has been possible in many cases to locate substations so that they could supply the trolley lines and also be used to control the 25 000 volt transmission lines. There are at present 32 substations which have attendants on duty at all times. All of the apparatus in these stations, most of which were built

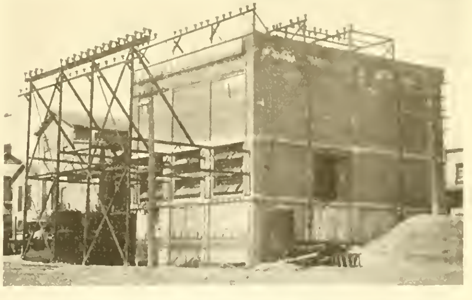

FIG. 6—SUBSTATION AT MCDONALD, PA.

The indoor equipment consists of a 2750 kv-a synchronous condenser, which drives a 200 kw generator to supply a small direct-current railway load; the switches and protective equipment for five 25 000 volt lines and for one 2200 and two 6600 volt circuits with induction regulators. Three 1500 kv-a transformers are located outdoors. This is one of the points where interconnection is made with the lines of the Duquesne Light Company.

between 1905 and 1915, is placed indoors in two or three-story brick buildings, except that in many instances the transformers are placed out doors. Provision has been made to "jumper out" each 25 000 volt

oil switch so that it may be disconnected for inspection or repair without interrupting service on the line which it controls. In many substations provision has been made to synchronize between the 25 000 volt lines. Each circuit in each substation is protected against lightning by means of low equivalent lightning arresters. There are 288 sets of arresters now installed on the 25 000 lines which makes an average of one set of arresters per two miles of pole line. Experience on the West Penn System indicates that there is considerable benefit in bringing a line conductor straight to an arrester and then taking it directly back on itself for a few feet. This is referred to as a "dip". The lightning seems to have a tendency to follow a straight path through the arrester rather than suddenly reverse through a 180 degrees turn. This effect may be noted especially on the low-tension arrester shown in Fig. 5. The wiring to the arrester is usually made of insulated wire and the two conductors are tied together.

Present practice is to install 25 000 volt apparatus outdoors, and low-tension switches, rotating machinery, regulators, meters, etc., in a building. Fig. 5 shows a cross-section of a typical installation for medium capacity semi-attended stations which require low-tension equipment.

The system power factor is approximately 90 percent as a result of the installation of considerable synchronous apparatus in the Company's own substations, and by so arranging rate schedules as to encourage customers to use synchronous apparatus and to operate it at high or leading power-factor. A 5000 kv-a synchronous condenser is installed at Washington, another at Crows Nest, and there are several smaller condensers scattered over the system. It would appear that it is economical to use condensers rather freely, especially at stations where there are several circuits which will benefit therefrom.

The generator of a 30 000 kw turbine unit is now being installed in the Windsor generating station to be operated as a synchronous condenser. The fields of the Windsor units are the limit to their capacity and considerable more load may be obtained from them by improving their power-factor. The steam end of the new unit will be kept on hand for emergencies.

The 25 000 volt lines were operated with delta-connected transformers at power stations and with neutral point isolated from ground until 1917. By that time the system had grown to such an extent that it was thought advisable to ground the neutral in order to decrease the damage caused by local failures, causing high voltage surges which sometimes gave trouble at points even remote from the location of the original trouble. The 25 000 volt neutral is now grounded at Connellsville, Springdale and Washington. Provision is also being made to ground it at the Windsor power station. At each of the four points the neutral is, or will be, connected to ground through a resistance of 28.8 ohms. It is thought that the use of a grounded neutral will also be of considerable benefit in isolating grounded line sections by the use of relays, which are now being installed.

The 25 000 volt transmission system is a very difficult one to relay, with its many loops, cross-connections and substations in series between power plants. A system of low-voltage relays* has been used for a number of years, with automatic circuit breakers which are locked so that they cannot open unless the voltage is below some predetermined value for which the low-voltage relay is set. This system of relaying was the most satisfactory one available at the time it was installed, especially for a system which is supplied from one power plant, which was the condition at that time. Now that there are three main power plants and one 66 000 volt substation supplying power to the 25 000 volt system, and that there has been a great improvement in the design and application of relays, a change in the relay system is being made, using induction type relays throughout. Inverse time limit overload, and inverse time limit reverse energy relays are being installed to get protection against short-circuits. Protection against grounds will be obtained by means of a single one ampere inverse time limit overload relay for each circuit, connected to operate from the unbalanced current between the three phases. One of the main difficulties in applying this relay system is the comparatively small ground current that can flow through transmission conductors and the resistance connected between transformer neutral points and ground. However, in view of the fact that current will be supplied to ground at four different points, it is thought that there should be sufficient unbalanced current flowing to the grounded section to trip out the switch at each end. The ground current will in nearly all cases be considerably less than short-circuit current, so that circuit breakers will not trip from overload in case of ground, and the difference between time settings on ground relays for several substations in series may be made large enough to afford positive selection in case of grounds.

At generating stations and main substations, the generators and transformers are protected only by balanced relays, which will operate only in case of trouble in the apparatus involved, but will not operate on overload. Balanced relay protection is also provided in some instances for house generators and for motors of motor-generator exciter sets.

Details of operating the power plants and transmission system, apportioning load between plants, locating troubles, etc. are supervised by a system operator, or chief load dispatcher, located in the Pittsburgh office, working through four district dispatchers, located at Springdale, Connellsville, Washington and Windsor, who in turn supervise the operation in their own districts.

The chief aim throughout the years of development of the transmission system has been to provide reliability of service. Power is supplied to the 25 000 volt

*Trans. A. I. E. E. Vol. XXXVI p. 409.

network at four points well distributed over the territory, each being located near a district having large load density, and tied in with the others over several transmission circuits. Connection can be made with the lines of the Duquesne Light Company at nine points, widely distributed over the territory, so that in emergencies either of the two systems has the use of the transmission facilities of both. Consumers may receive power over more than one line, so that the failure of any one section will not cause interruption to service, except for a few single line extensions into new territory where it has not yet been possible to provide duplicate service. All of the lines are provided with overhead ground wires, and lightning arresters are used very liberally, one set of arresters being provided, on the average, for each two miles of pole line. There are many switching points distributed throughout the transmission system where operators are kept on duty at all times. An extensive system of relays for sectionalizing the lines automatically is provided and is now being revised to take advantage of the latest developments in the art of applying relays. A private telephone circuit is carried on all transmission lines so that it is possible to reach most substations over more than one private line and patrolmen may communicate quickly with load dispatchers from any point along the lines. The territory is also served by the Bell and several independent telephone systems whose service may be used in case communication cannot be had over the private lines. The distance between poles is comparatively short, and the pole top construction is extremely rugged, so that mechanical line failures are reduced to a minimum. The line insulation is so high that it is necessary to have manufacturers provide special bushings for transformers and oil switches, in order that such insulation will not be the weakest part of the system.

The reliability of service, which may be obtained from a power transmission system constructed and operated along most modern lines, has reached the point where the probability of interruptions has become so remote as to warrant consumers, distant from power plants, to expect service practically as reliable as from plants nearby or from their own plants.

The Generating System of the West Penn Power Company

G. G. BELL
Manager, Power Department
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THE greater part of the power produced by the West Penn Power Company is generated at three stations. The Connellsville station is located in the southeast part of the territory and carries the load in what is commonly called the "Coke Region" of southwestern Pennsylvania. Windsor station is located on the Ohio River and carries the load between the Ohio and Monongahela Rivers. The Springdale station is located on the Allegheny River above Pittsburgh and carries the load in West Penn territory north of a line drawn east and west through the City of Pittsburgh.

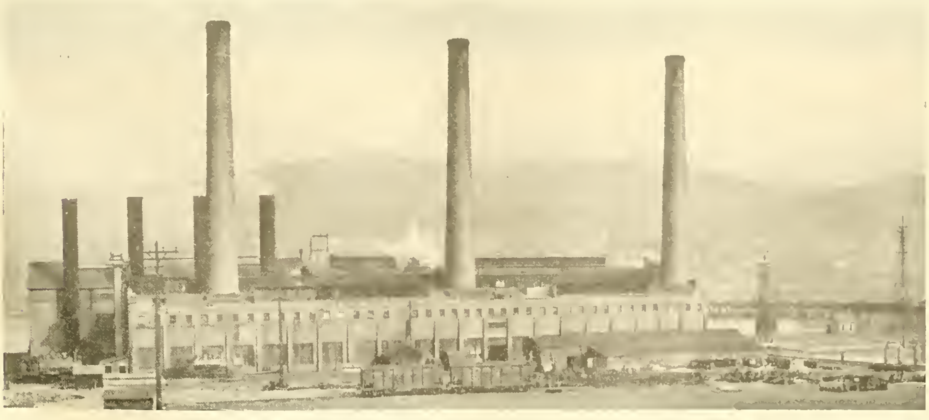


FIG. 1—CONNELLSVILLE POWER STATION

The Pittsburgh District is fortunate in having large fields of coal in proximity to ample supplies of circulating water, so that there are at present in this district, either in operation or under construction, five stations each laid out for a minimum of 100 000 to a maximum

of 300 000 kw ultimate capacity, which will draw their coal supply from mines located so as to deliver coal directly to the power house, or connected to it by short privately-owned railways. The advantages of such an arrangement are numerous.

The location of a power house at the mine mouth eliminates the danger from strikes on transportation systems which may deplete the coal storage at a time when it should be built up to take care of irregularities in the car supply caused by the greater demand in the severe winter weather.

Interests affiliated with West Penn Power Company were fortunate in securing large tracts of coal at two points in its territory. At one of these, in the northern portion adjacent to the new Springdale station, the vein has an average thickness of 7 feet 5 inches, with an exceptionally good roof. The other tract, at Windsor, West Virginia, on the Ohio River in the Panhandle District of West Virginia, has an average thickness of 4 feet 6 inches and supplies coal to the two power houses there constructed under one roof and owned by the West Penn Power Company and the Ohio Power Company.

Considerable of the coal mined and sold on the market, particularly from the smaller mines that are operated only on the high-priced market, is not prepared. The tipple as built at Springdale and the new tipple about to be constructed at Windsor are both designed so that the coal may be picked before it is weighed for the miner in which case the miner will be paid only for the clean coal which he loads. The presence of fire-clay or other foreign matter which fuses at a low temperature has a very undesirable effect and considerably reduces boiler capacity and in addition lowers the efficiency on account of the increased coke passed out with the ash and the greater amount of excess air necessary to burn the higher ash coal. In the case of the mine at Windsor, this arrangement will not add anything to the first cost of the tipple and it is expected that the cleaner coal obtained will have a very beneficial effect on the efficiency of the station and the ease with which it is operated. When a station is supplied with a single grade of coal, the continual adjustment of the stokers, to adapt them to varying grades of coal, is eliminated.

CONNELLSVILLE STATION

The Connellsville station is located on the Youghiogheny River about 35 miles in an air line from Pittsburgh. This is the oldest plant of the three. The present peak capacity is about 60 000 kw. There are seven turbogenerators, the largest two being of 18 000 kw capacity each, and the other five ranging in capacity from 1000 to 6000 kw, normal rating. The major part of the steam is produced in four boilers of 1372 hp capacity each, each boiler being equipped with an 8800 sq. ft. economizer and a 14-retort stoker. The remainder of the steam is produced in thirty-two boilers each of 372 hp capacity.

FIG. 2 GENERAL VIEW OF POWER STATION, OUTDOOR SUBSTATION

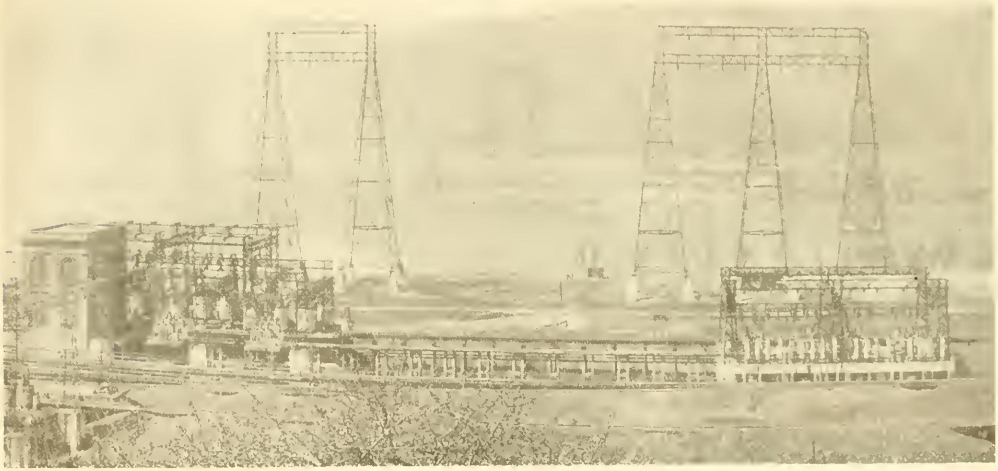
The average monthly load factor on the West Penn System is about 63 percent. The average load factor on the Connellsville station, on account of its being the least efficient of the three stations, is about 40 percent. The base load factor on the system will be about equally divided between the Windsor and the Springdale plants.

Lump coal to the amount of 35 000 tons is at present in storage either on the ground or in privately owned railway cars. This is slightly in excess of two months requirements at the present rate of consumption. The West Penn Power Company during the recent car

shortage purchased seventy 55 ton hopper cars to transport coal for this power house and which were specially designed so as to permit the removal of more than 90 percent of the coal by means of grab bucket. This is a difficult matter in the ordinary hopper car as there are so many struts that they interfere with the operation of the bucket. These cars have been loaded with lump coal and withdrawn from operation until the next car shortage. Fig. 1 shows a photograph of the Connellsville plant. Two 20 ton locomotive cranes are utilized to handle the coal in and out of storage. The company has 60 acres of low-lying land at this point which is being utilized for ash disposal.

WINDSOR STATION

The Windsor power station is also located about 55 miles in an air line from Pittsburgh, but in a southwesterly direction. The installed capacity at present consists of four 30 000 kw units, one of which is owned by the West Penn Power Company and three by the Ohio Power Company. Each turbine is supplied with steam by four 1262 hp boilers, each equipped with an 8800 sq. ft. economizer and a fourteen-retort stoker. The auxiliaries for this plant are all motor-driven, the only steam-driven units being the boiler-feed pumps, each generator having a direct-connected exciter. Water enters the economizers at from 100 to 120 degrees. Power for the auxiliaries is supplied by means of house transformers.



AND TRANSMISSION TOWERS AT WINDSOR, WEST VIRGINIA

The tipple from which the coal is received is about one-third of a mile south of the power station, connected by steam railroad owned and operated by the power house company. A new mine opening adjacent to the power house is at present being driven and a new tipple, belt coal conveying and storage equipment are being provided, which will eliminate the present railway between tipple and power house and permit storing or reclaiming 140 000 tons, about two months' supply of coal for the contemplated capacity of this station, viz., six 30 000 kw units. Work on these improvements, having a maximum capacity of 500 tons per hour, has been started and they will be in operation before the end of the year.

At the Windsor power station, the new coal handling scheme will deliver coal to the boiler bunkers direct by means of belt conveyors, thus effecting a very considerable reduction in the number of men employed to handle the coal between the mine opening and boiler bunkers.

SPRINGDALE STATION

The Springdale station is located on the Allegheny River about thirteen miles in an air line from Pittsburgh. The initial installation consists of two 25 000 kv-a units and five 1529 hp cross-drum boilers, 16 tubes high and 42 wide. As the power-factor on the West Penn System is around 90 percent, both the Windsor and Springdale stations are operated above 90 percent power-factor, the lagging current being absorbed by the Connellsville power station. This enables the machines at Windsor and Springdale to be run at practically unity power-factor.

The rivers in the Pittsburgh District, like others having a quick run-off, are subject to ice gorges and, especially in the fall, carry large quantities of leaves and debris. The intake, when operated under ordinary conditions, is divided into four sections, two up-stream and two down as shown in Fig. 12. As each unit has two circulating pumps, one circulating pump is supplied with water from each of the two sections. Gates are

provided by which the discharge tunnel may be closed and, by opening other gates between the discharge tunnel and the intake, the water, after passing through the condensers, is discharged through the upper intake section. By this means the water is recirculated during cold weather. This arrangement has proved very effective at the Connellsville station in overcoming ice and debris troubles. When there is ice or debris the water flowing in the river has enough volume and the temperature is low enough to allow the maintenance of a good vacuum provided a sufficient quantity can be drawn through the screens. The ice readily chills the water discharged by the condensers, permitting it to be used again. Leaves running in the river are handled by the rotary screens but the amount to be removed from the circulating water is reduced by recirculation. In addition to the advantages of recirculation, the double intake system permits a partial cleaning of condensers by shutting down one circulating pump and reversing the flow of water through the condenser, thus cleaning one-half of the inlet section of the condenser head at a time while it is in service.

It was thought that it would be necessary to put in a line of sheet piling to divert the discharge water away from the intake, but the present quantity of water being handled by the intake is such a small part of the river flow that this has not been found necessary. While there was very little ice last winter, the indications are that the Springdale plant is very favorably located in that it is just below a bend in the river and the ice and leaves seem to hug the farther shore.

Consideration of the simplification of the station, decreased maintenance, elimination of small piping with the consequent reduction of steam leakage and make-up water resulted in the installation of motor-driven auxiliaries supplied with power from a house generator, due to the increased economy of such an installation as compared with steam driven auxiliaries. This amounts to an average saving in the working limits of the plant of two percent, besides an increase of two percent in the output of the main units on account of the smaller percentage of the main unit capacity being required to supply electric power to the auxiliaries in order to maintain the heat balance.

While motor-driven auxiliaries are more desirable from an operating and maintenance standpoint as ordinarily supplied with power, they are not so reliable, as they introduce one more link between the source of

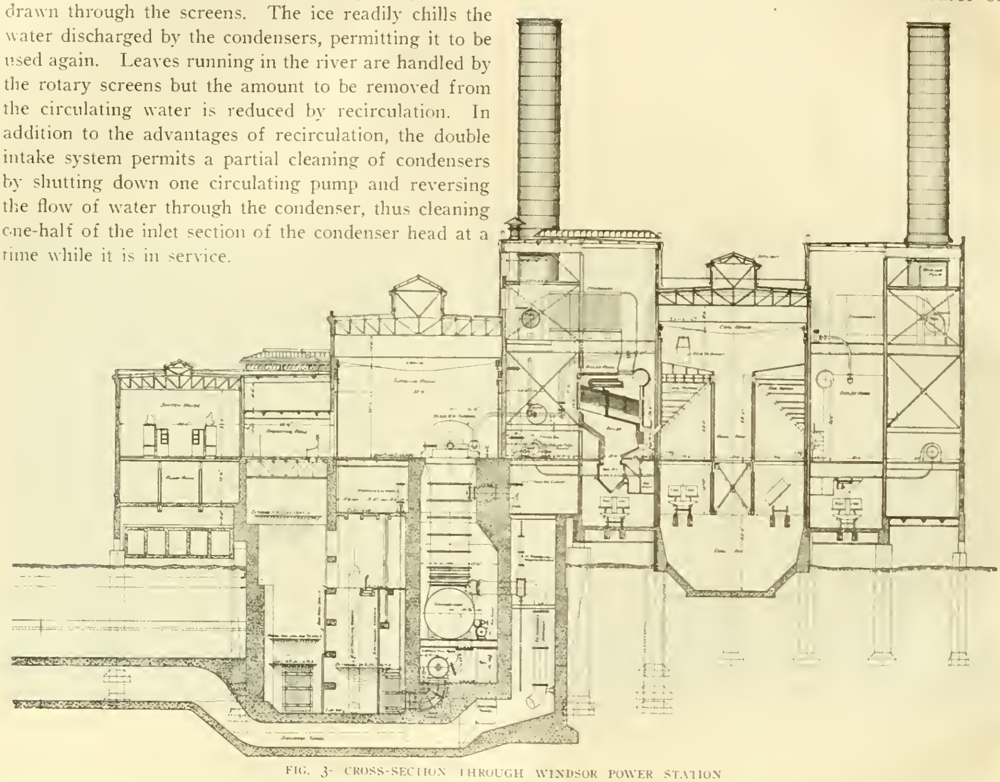


FIG. 3—CROSS-SECTION THROUGH WINDSOR POWER STATION

power and the driven unit. To overcome this difficulty and to permit the operation of the large turbines in case of failure of one of the auxiliaries, duplicate circulating pumps, condensate pumps and air pumps are provided. Either circulating pump, when run by itself, will supply approximately two-thirds of the amount of water which the two will when operated together. This increased capacity of the pumps is due to the reduced frictional resistance. The average yearly cooling water temperature is about 55 degrees. Nine months in the year it is below this figure, and three above, so that for a greater part of the year, even when carrying full load on the machines, there is very little advantage from a vacuum standpoint of running more than one circulating pump. The condensate pumps

are each of 100 percent capacity, only one of these being operated at a time. An interruption could occur to the condensate pump for several minutes without the water level in the condenser becoming so high as to affect the vacuum on the machine seriously.

Each condenser is provided with a LeBlanc air pump, with a steam exhauster as an emergency relay. It was at first planned to use the exhauster to raise the water for priming purposes but, on account of the complication in piping and the liability of getting raw water mixed with the condensate, this plan was abandoned and separate four-inch steam exhausters were placed on each condenser. A short interruption to the air pump, as with the condensate pump, is not serious. For this reason, it has not been considered necessary to operate duplicate units, as the duplicate unit can be started before the interruption to the condensate pump or air pump will have a serious effect on the main unit.

In order to get a reliable source of power for the electrically-driven auxiliaries and to prevent a total interruption in case of any trouble, two separate sources of power are provided; viz., a house generator and house transformers, one circulating pump and one condensate pump being supplied from the house generator and the others from the house transformers which step the generator voltage down from 11 000 to 2200 volts for use in the larger motors throughout the plant. Practically all other auxiliaries have two sources of power and can be transferred from one to the other in order to maintain sufficient load on the house generator to heat the feed water to 210 degrees.

These include the low service pumps, sump pumps, boiler room auxiliaries, motor-driven exciter set and the motor-driven boiler-feed pumps. Both the motor-driven exciter and boiler-feed pumps are normally operated from the house generator bus, the exciter set being tied in non-automatically, but protected by balanced relays so that in case of internal trouble it will be disconnected from the source of power. In case the house generator is not operating, the two 2200-volt busses are operated in parallel.

The motor-driven exciter set is duplicated by a steam-driven exciter set. As the thermal efficiency of the house generator is considerably higher than that of small high-speed turbines, there is a substantial saving in operating even the boiler-feed pumps by means of motors, although a turbine-driven boiler-feed pump is provided to supplement the two motor-driven outfits. This saving amounts to an average of 100 kw throughout the range of capacity of the pump. The control of the motor-driven boiler-feed pump is through an excess pressure reducing valve in place of the ordinary excess pressure valve controlling the steam supply to the turbine-driven boiler-feed pump.

At the option of the operator, the boiler room auxiliaries can be transferred from one bus to the other in case of failure of either source of power. While from an operating standpoint there is greater liability of trouble if the house generator is operated in parallel with the main units, yet the heat balance can be more closely adjusted when all generating units are operated in parallel. This may be done automatically if desired by the installation of a thermostatic control. If the house generator and house transformers are tied together, relays are provided so that in case of an excess output by the house generator it will be disconnected from the house transformers and carry its own load irrespective of disturbances to the house transformers, which might cause some of the motor-driven auxiliaries connected to the house transformers to drop out of step. As long as one circulating pump is in operation, vacuum can be maintained on the main unit. Originally it was planned to install check valves between the circulating pumps and the condenser in order to prevent one pump discharging water through the other in case of failure. Since starting up the plant, it has been found that the maximum speed at which one of these circulating pumps can be run when reversed and running as a turbine is about one-third of its normal operating speed.

FIG. 4—VIEW OF SPRINGDALE STATION DURING CONSTRUCTION
Showing water intake at the left and mine tipple and crusher house at the right.

This would mean that one-third of the water discharged by the circulating pump in operation would be by-passed through the reversed circulating pump and that the condenser would be supplied with about one-half of its maximum quantity of circulating water. Under average conditions this would reduce the vacuum from 29 to 28.4 inches, which would not cause sufficient capacity reduction to affect the service seriously.

As the power house is extended, additional house generators will be installed which will have sufficient full load. By carrying the motors which require the greatest reliability in the source of power on the house generator and getting the additional exhaust steam over what the house generators can furnish by bleeding the main unit, the most reliable and most economical arrangement of power station auxiliaries is obtained.

In order that a unit can be started quickly in case the condenser becomes vapor-bound, hydraulically-operated gate valves are provided not only on the suction of the pump but on the discharge as well. This allows the

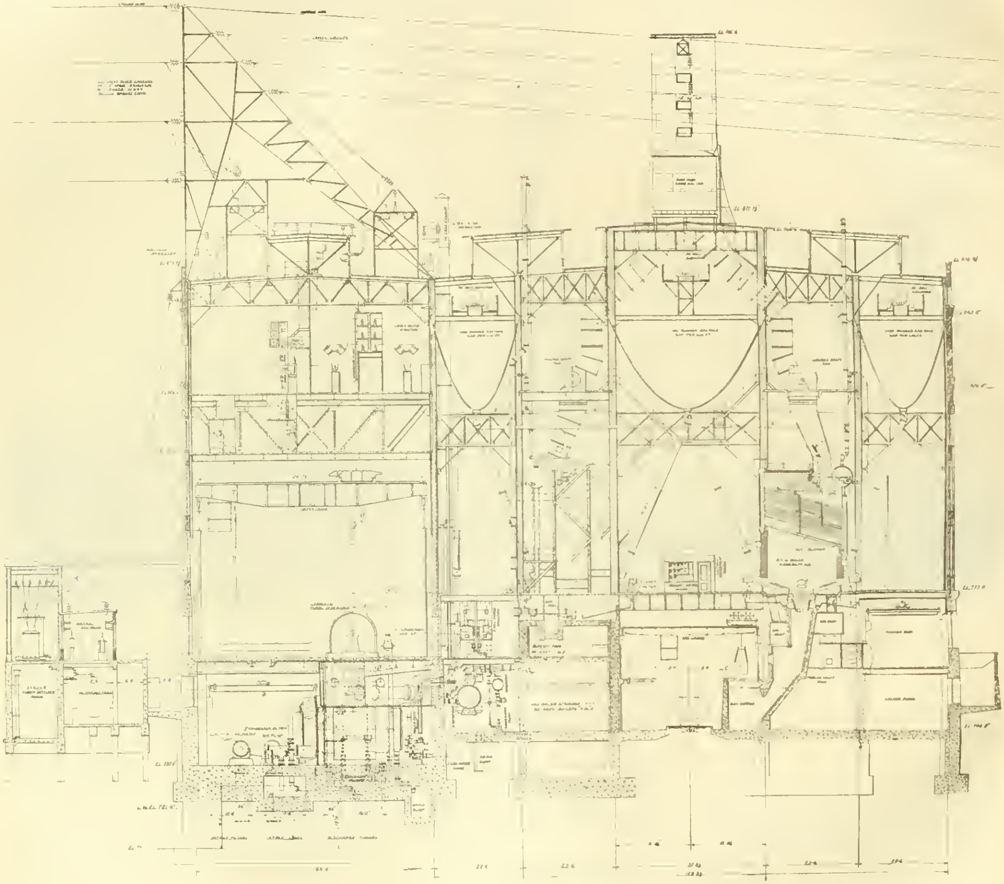


FIG. 5—CROSS-SECTION OF SPRINGDALE STATION

capacity to carry the electric-driven auxiliaries which are most vital. The remainder of the exhaust steam will be provided by bleeding the main turbogenerators. This bleeding will be required only at loads above the point of maximum efficiency of the main unit and thus will reduce the congestion in the low pressure stages of the turbine, as experiments show that a considerable amount of steam can be removed from the congested area of the main turbine without increasing the steam demand. This is only true at approximately air to be exhausted from the circulating pump and the water to rise so as to cover the runner, without exhausting the vapor from the condenser. A hydraulically-operated gate valve is also placed in the discharge line to permit of repairs to the condenser at times of flood water. The maximum flood stage at Springdale is 32 feet, at Windsor 52 feet and at Cincinnati 72 feet.

The use of electric-driven auxiliaries affords a good opportunity to determine the amount of power consumed by auxiliaries. In the Windsor station the per-

centage of power runs from about $5\frac{1}{2}$ to $6\frac{1}{2}$ percent of the total power generated. The estimated consumption for Springdale at various loads will be in the neighborhood of 6 percent. The percentage of power used by the induced-draft fan is approximately uniform at one percent of the gross output of the station.

The reason for installing induced-draft fans was that, on account of the high first cost of the boilers installed, it was desirable to secure a very large steam output which called for so high a draft that the only practical means of securing it was by means of induced draft fans. In addition, there is no individual factor which will so greatly increase the maintenance cost as insufficient draft. By the installation of mechanical draft, ample spare capacity could be installed to take care of dirty boilers. This excess capacity has already demonstrated its advisability.

build the thinner portion, particularly in front of the lower end of the headers. A steel plate sloping away from the combustion chamber has been placed along the front of the mud drum and the brick wall bonded or tied to this plate. The first boiler put in operation has seen some eight months' service. It has been taken off the line quite frequently for cleaning, but the walls, with the exception of the minor change to the top, show no signs of deterioration, so that as far as capacity is concerned the walls are not the limit.

Normally two boilers are operated to carry about 22 000 kw load on one machine, or in excess of 300 percent rating, the load factor on the unit being in excess of 80 percent. The furnace temperatures as obtained by an optical pyrometer when running at this high rating are below 2800 degrees F.

Boiler Room Auxiliaries—Space has been provided in the station for economizers. The present induced-draft fan system could take care of the increased draft required by the present boilers when equipped with economizers, as the gas volume would be decreased sufficiently to offset the increased draft required. An investigation of the stations at present operated by the company and equipped with economizers indicates that the installation of the house generator in these stations would increase not only the reliability of the motor-driven auxiliaries but would increase the economy and boiler capacity of $2\frac{1}{4}$ percent and in turbine generator capacity of 5 percent. These advantages would pay a handsome return on the additional investment required for a house generator, besides having the additional advantage of a more reliable source of power. As a result of this investigation and of better air extraction at 210 degrees it was decided to heat the feed water to 210

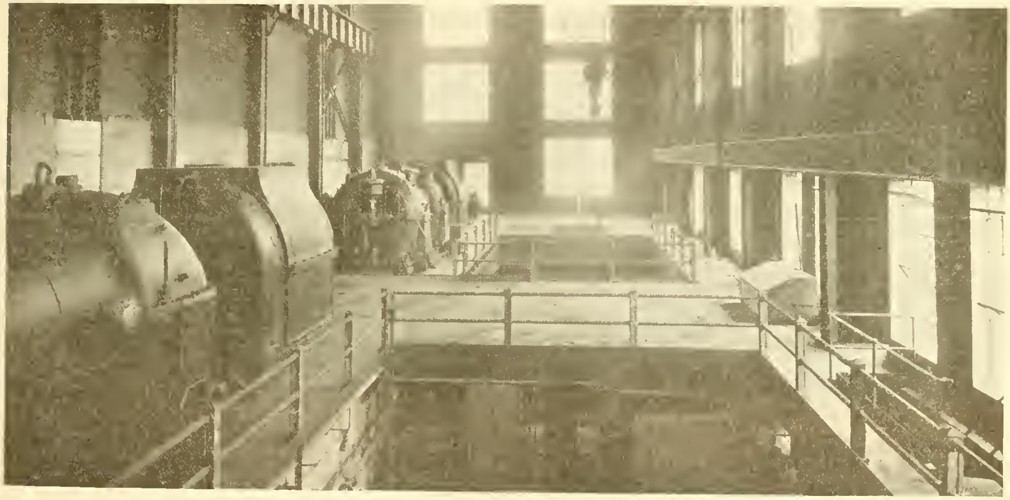


FIG 6—INTERIOR OF TURBINE ROOM AT SPRINGDALE
Showing condenser wells. The generator leads are copper bars supported on 25 000 volt insulators in the left wall.

The boilers are designed for 350 pounds pressure, and 235 degrees maximum superheat. At present they are being operated at a drum pressure of 325 pounds, and are delivering steam to the turbines at about 650 to 675 degrees. The boilers are equipped with two 13-retort stokers with double clinker grinders. The average coal at this plant contains about 10 percent ash. With coal of this type the percentage of combustible in the ash is very low, even in ordinary operation.

In the first four boilers installed, the front header is set 16 feet above the ground. The front and rear walls are bonded to steel framework by tile, the side walls being 32 inches thick at the bottom and decreasing to 22 inches at the top. All four walls are air ventilated, and there has been very little deterioration of walls where they have a thickness of 22 inches or more. In the front and back walls it has been necessary to re-

degrees, leaving the question of installing economizers to be settled at a later date.

It was found necessary to provide a heating system in the plant, particularly in the boiler room to prevent a general freeze-up of instruments and piping. For this reason the instruments are placed on the outside of a small operating room located on the main boiler room floor, the inside of the room being heated. The vacuum system of heating with exhaust steam is used.

All boiler room auxiliaries are driven by alternating-current motors. The induced draft-fan, for the sake of reliability and in order to reduce the length of the shaft, is divided into two sections. Two single-suction induced draft-fans are installed in place of a double-suction fan, the two fans being joined by a flexible coupling. Two motors drive this double unit, a 175 hp 2200-volt slip-ring motor on one end and a 400 hp 2200-volt slip-ring motor on the other. The 175 hp motor has sufficient capacity to operate the unit to 325 percent rating, and is connected to the fan by means of a uniflex coupling. In case greater capacity is required, or the drop throughout the boilers increases, the 400 hp motor is started and, when brought up to approximately the maximum speed of the 175 hp motor, the second notch of the control cuts out the 175 hp motor and closes the circuit of a magnetic clutch, transferring the load to the 400 hp motor. This arrangement gives increased reliability and economy, as the 175 hp motor will ordinarily be able to carry the full output required of the boilers. In case of trouble to any section of the fan unit, from two-thirds to three-quarters of maximum capacity can still be maintained from the boiler.

The stoker motors are three-phase, 60-cycle, 440-volt induction, pole-changing type, and have a maximum speed range of 4 to 1.

The forced-draft fan is driven by a 175 hp, three-phase, 2200-volt brush-shifting motor. This is an alternating-current motor with direct-current characteristics. Only one motor is provided per boiler. The forced-draft air ducts for the boilers are inter-connected and separated by dampers. In normal operation each one is run separately while, in case of a breakdown, the dampers are opened and a number of boilers are operated together on a continuous air duct.

The fan and stoker motor controllers are operated by pilot motors which are controlled by push buttons on the main control board or directly at the motor. The pilot motors are arranged for either hand or automatic control. At the present time two boilers are being equipped for automatic control, the induced-draft fan motors and the stoker motors being controlled from the steam pressure and the forced-draft fan, which permits close regulation, being operated from the furnace pressure. As there are two stoker motors per boiler, the control for these stokers is designed so that the relative rate of feed of the two stokers can be adjusted by hand, to allow for differences in fuel requirements of the two sides of the furnace.

The wind box of the boiler is divided into eight sections, each having its own damper which is adjusted to reduce the wind box pressure under sections of the fire that are too thin.

FIG. 7—GENERAL VIEW OF SPRINGDALE POWER HOUSE, ALLEGHENY RIVER.

The coal is conveyed from the mine on the right side of the river through headings in the coal 60 ft. under the river to the tipple on the power house side.

The supply of air to the boilers is a problem which is not always given the attention it deserves. At maximum rating 100 000 cu. ft. of air per minute is required for each boiler at the Springdale station, while about 75 000 cu. ft. of air per minute is required under ordinary operating conditions. This is about the amount required for cooling each generator and, as two boilers will carry the maximum rating of each generator, the air for the boilers next the turbine room is taken from the discharge of the generators, while the air for the boilers farthest removed from the turbine room is drawn through a duct from the outside. In this way none of the air supplied to the boilers is taken from the ash cellar. The usual arrangement has the disadvantage that, in cold or foggy weather, the vapor in the ash cellar becomes so thick that there is danger of accident to the operators, especially if the stokers are so constructed that, when run at high ratings, the gases

escape through the ash pit doors or openings for operating mechanism.

In some of the power houses of the West Penn Power Company the ashes are dumped into hoppers and thence into narrow-gage or standard-gage cars, transported by electric or steam locomotive and dumped over the property. With such arrangements, when boilers are being pushed and especially at times of cleaning, there is a considerable amount of corrosive and combustible gas that escapes through the ash pit doors. At times when the fire is being dumped this gas will ignite. The action of the heat, together with the corrosive action of the sulphur, has a destructive effect upon iron work. It has been necessary to replace some of the iron work in these plants after three years' use, or to cover it with gunite.

At the Springdale station, these gases are all confined and there is no iron work for them to come in contact with. No gases escape into the ash cellar and there is no movement of air in the ash cellar except such as is necessary for ventilation. The ash-handling, instead of being one of the most laborious and unpopular jobs, is one of the easiest and most inviting jobs around the plant. One crane operator in two hours per day readily handles the ash output of the present installation. However, on account of the deep excavation that has to be made for the foundation it is planned in the extension of the power house to make the ash pit twice as deep. This can be done at comparatively little additional cost. With the present stoker operation this pit capacity will afford several days' storage for ash. In the original installation, the clinker grinders are driven from the stoker crank shaft. This is being changed in the installation of the fifth boiler, the drive being taken off the speed shaft. This will permit operation of the grinder, in case of formation of excessive clinkers, without feeding additional coal into the boiler. The capacity of the coal spouts is such that it takes one and one-half hours' operation of the stoker to empty them.

Ash Disposal—Facilities for dumping ashes are available. West Penn interests own lands suitable for the disposal of the ashes and rock to be produced from the 4000 acres of coal controlled by their affiliated company. Part of this disposal is eighty acres of land which surrounds the power house. The remainder is a ravine adjacent to the power house, where an ash fill 200 feet deep or more can be made. When it is necessary to use this latter disposal, it is possible that an aerial tramway may be more economical than locomotive and dump cars for disposal of the ashes. The present ash loading system at the Springdale power station can easily be modified for this type of equipment.

The coal tipple is located about 250 feet from the power house. Coal from the mine or from the track hopper is delivered through the tipple to two, but ultimately three, four-roll crushers, any two of which will have sufficient capacity to take care of the maximum capacity of the picking tables or track hopper. The coal is screened, the fine coal by-passing the crusher and dropping upon the 42 inch inclined belt conveyor leading to the bunkers, the crushed lump coal dropping on top of the fine coal in order to reduce wear upon the belt. As each boiler is stokered on two sides, three bunkers are necessary in the plant. The bunkers are of the suspended type and have a total capacity of about 800 tons per boiler. This is equal to about five days' supply at an average rating or ten days' supply at a low load factor.

COAL MINE LOCATION, TOWN SITE, SHOPS AND MATERIAL HOIST

The town site and coal mine are located on the opposite side of the river from the Springdale plant. The town of New Kensington is shown in the distance. These two illustrations form one continuous view.

This inclined belt has a maximum capacity of 500 tons an hour. For the present, it is geared down to one-half this capacity. There is a 250 ton an hour belt, conveying coal over each of the three bunkers, the coal being distributed throughout the length of the bunker by means of automatic trippers. As the coal is discharged from the top of the inclined belt, a sample is taken automatically. This is crushed in a coal sampler and five percent of it retained for analysis. In this way a continuous record of the coal fed to the power house is obtained.

The coal is fed from the bunkers to the boilers by

means of three spouts for each stoker. The spouts on the front and back of the boiler are staggered, so that any tube in the boiler can be drawn from one end or the other without interfering with the coal spouts.

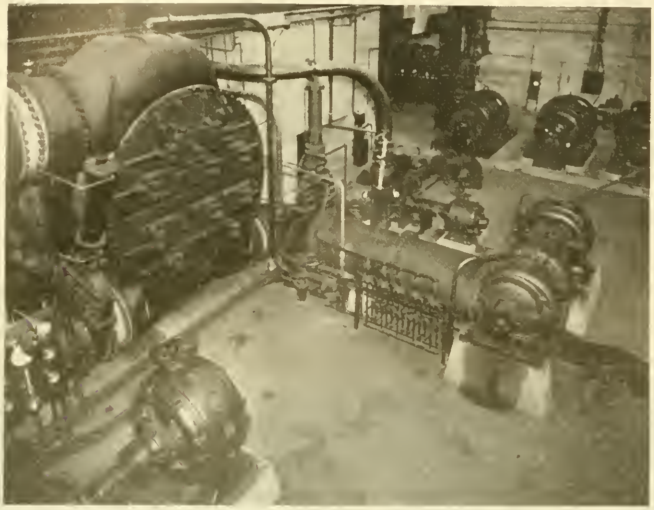


FIG. 8—CONDENSER PIT

Showing railway sets and control for hydraulically-operated valves. All these auxiliaries are served by cranes.

Preparations are being made at Springdale for a large coal storage. The present plans propose a bridge of 250 to 300 feet which will run on tracks parallel with the river of any length up to a maximum of 1500 feet. This storage will be extended as the plant develops, so as to keep two months' coal requirements on hand at all times. The bridge will also provide a means of unloading coal brought to the plant in barges either to storage or direct to the track hopper and thence to the crushers and power house bunkers. At present coal is handled to and from storage by means of locomotive cranes.

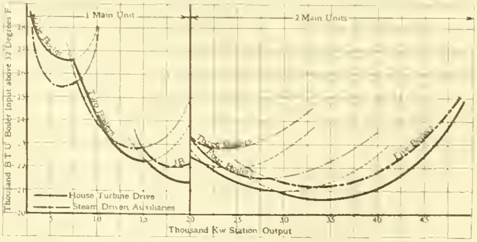


FIG. 9—COMPARISON OF POWER REQUIRED FOR AUXILIARIES WITH ELECTRIC MOTOR AND STEAM TURBINE DRIVES

The plant piping is simple. All steam piping four inch and larger is welded, the joint first being vanstoned and equipped with flange, which is recommended for adoption as the 800-pound hydraulic standard. On the smaller piping, trouble from steam leaks has been experienced with screwed unions, and it has been necessary to go to an 800-pound hydraulic union and to weld a considerable number of the threaded joints. In the later piping, wrought iron has been substituted for steel, as more perfect threads can be cut in the wrought iron. All boiler feed piping is wrought iron with welded flanges of 800-pound hydraulic standard.

Pilot gauges are used throughout the plant to indicate steam pressure. Gages record the pressure and temperature of the feed water and steam, the temperature of the exhaust steam from the main units, and of the inlet and outlet circulating water and condensate. Boiler meters measure steam flow, air flow, and draft in the furnace and other meters measure the quantity of steam, together with the pressure and superheat, supplied to each turbine.

As the boilers will operate at a high rating, pure feed water is essential. All water used in the plant, other than circulating water for condensing purposes, will be treated with lime to neutralize the acid, which occurs at time of low flow in the river, and also with alum and then filtered and chlorinated so as to produce a water safe for domestic use. This treatment will prevent corrosion and reduction of the area of the low pressure piping throughout the plant. The make up water for the boilers is evaporated, two evaporators of 10 000 pounds capacity per hour each being installed, which when working single effect will supply about 3½ percent of the maximum amount of water required by the generating equipment. On account of the smaller number of steam-driven auxiliaries, the make-up is probably not much in excess of one-half of this amount. The evaporators are operated between two pounds back pressure and 23½ inches vacuum. This is the highest

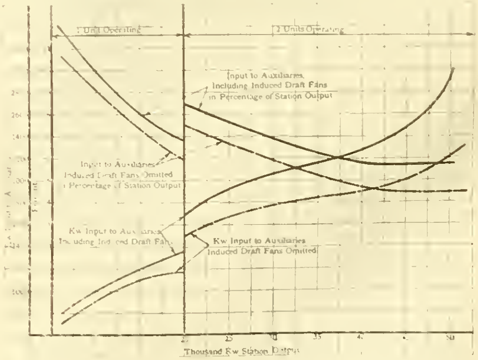


FIG. 10—POWER REQUIRED FOR AUXILIARIES WITH AND WITHOUT INDUCED DRAFT FANS

vacuum which can be obtained in the evaporators when evaporating the maximum amount of water required, using the condensate from the main turbines as cooling water. The condensate after passing through the evaporator condensers is conducted to two jet condensers, where it meets the remaining exhaust steam from the house generator and is heated to approximately 210 degrees.

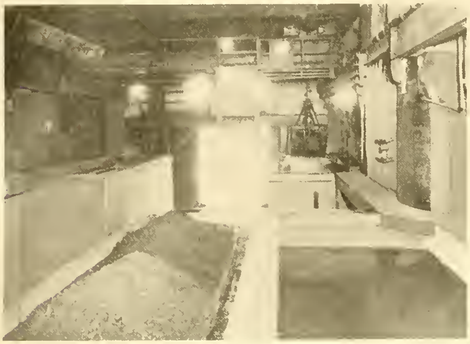


FIG. 11—ASH BASEMENT

Showing submerged hoppers and crane with 1.5 cu. yd. perforated grab bucket for handling ashes.

The statement is more or less generally made that the elimination of air from water will reduce the amount of corrosion in boilers and economizers. It was with this idea that the heating and evaporating equipment in this plant was installed. Tests under operating conditions prevailing in the plant during the latter part of February and March 1921 indicate that at approximately 210 degrees there is a very small amount of air in the water but that this increases rapidly as the temperature decreases. There is a further indication that practically no air is extracted in the low-pressure evaporators. It is only when the water is heated to approximately 210 degrees at atmosphere pressure that there is anything like a complete extraction of the air. It is possible that similar results may be obtained at lower temperature and corresponding absolute pressures but as yet this has not been demonstrated. An interesting fact is that the temperature of the exhaust steam from the house generator is about 260 degrees and from the boiler feed pump is about 400 degrees at full load, showing that, with the less efficient expansion, the steam exhausted from these small turbines is highly superheated. The troubles which previously had been encountered with these small turbines when supplied with high temperature steam, which necessitated redesigning so as to eliminate expansion troubles, together with the greater maintenance not only of the turbines but of the reduction gears, were given great weight in deciding to install the house turbine and motor-driven auxiliaries.

One evaporator has been opened twice in the eight months it has been operated. When first opened, there were indications that the water level was not high enough. After this had been increased and the coils submerged and the evaporators operated for another three months, they were again inspected and no more evidence of scale was found than could be removed continuously by the cracking process. The amount of water evaporated is controlled by the level of the water in the evaporated water tank. When the water gets below a certain level, exhaust steam is admitted to the evaporator coils. The evaporated water tank is interconnected with the jet condenser heaters.

The heaters are equipped with steam ejectors, which are operated for the dual purpose of extracting the air and of running at a slight vacuum, provided the load on the house turbine is not sufficient to heat the feed water to 210 degrees. The exhaust steam from the various ejectors on the heaters, evaporator condensers and from the main units, when they are used, is collected in a surface condenser, the condensed steam being returned to the evaporated water tank and the air being allowed to escape through a vent to the atmosphere. The condensate from the main turbines is used as a cooling medium.

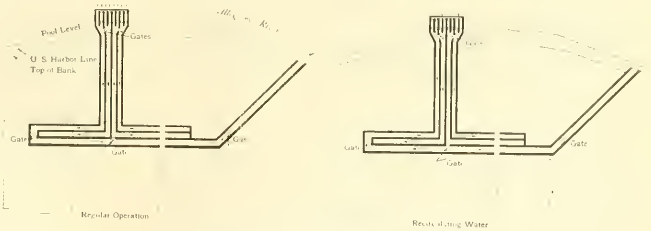


FIG. 12—WATER INTAKE AT SPRINGDALE

At the left the gates are shown in normal position. At the right they are shown in position to recirculate part of the water during extremely cold weather, preventing freezing at the screen.

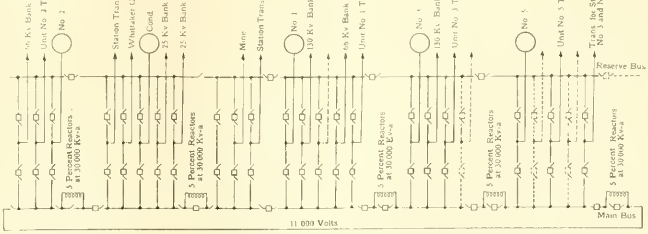


FIG. 13—11 000 VOLT RING BUS AT WINDSOR POWER STATION

Our experience with the low-pressure evaporator would indicate that a single-effect evaporator, using

steam between the limit specified, will work satisfactorily and, if the operation is given proper attention, will be self-scaling. The installation of a single-effect evaporator with jet condensor heater will simplify the station piping, reduce the first cost and be easier to operate.

Each turbine is being equipped with a continuous oiling system, 40 percent of the oil in each turbine being passed once an hour through a filter, having a maximum capacity of about 300 gallons of oil an hour. Large oil tanks are provided, into which the oil from any machine can be emptied. A centrifugal oil separator is provided, to clean the oil under these conditions. The older turbine oil is used throughout the plant for lubrication of the various motor and auxiliary bearings.

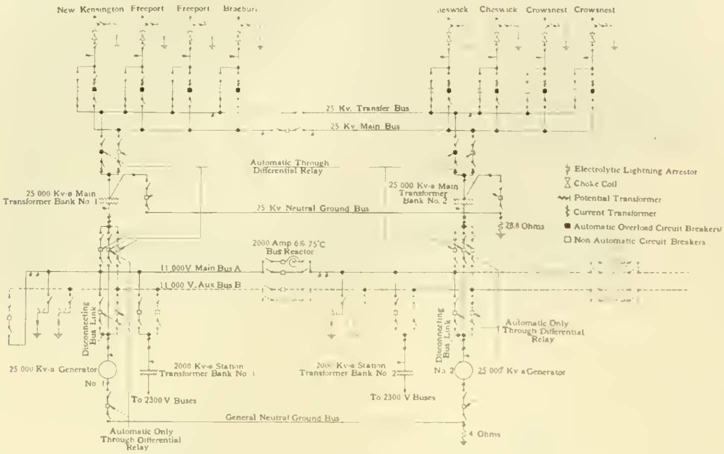


FIG. 14—MAIN WIRING DIAGRAM OF SPRINGDALE POWER STATION

A machine shop is provided, in which the following tools will be placed: 48 in. lathe, 24 in. lathe, 3 foot 6 inch radial drill, 25 inch post drill, 12 inch and 4 inch pipe threading machine, hack saw, 24 inch shaper, and 200-ton hydraulic press.

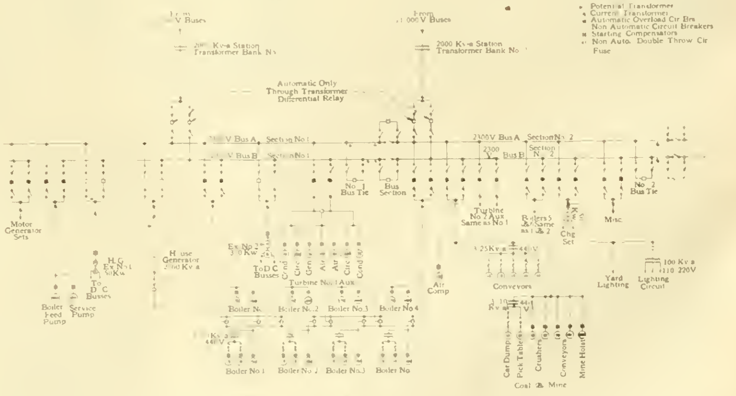


FIG. 15—DIAGRAM OF STATION AUXILIARIES AT SPRINGDALE

Particular emphasis has been placed in the design of the plant on having all machinery accessible for handling. The circulating pumps, air pumps, exciters, railway sets, and motors are all provided with crane service or trolleys, which will permit of readily repairing these various units. A locker room and wash room for 150 employes is located in the basement close to the machine shop. A small sewage disposal plant is provided sufficient for 250 to 300 employes.

ELECTRICAL INSTALLATIONS

The Connellsville plant was started in 1902 to furnish 25 cycle railway service to the original properties of the West Penn Railway System. When the 60 cycle rotary converter was developed, the 25 cycle system was abandoned and everything changed to 60 cycles, as this frequency had been adopted in the additional installations to furnish energy for lighting and power.

The switching apparatus in this plant was entirely overhauled in 1916, when the last 19 000 kv-a generator was installed, the main change being that each generator was given its individual transformers and arranged for paralleling on the high-tension bus only. As the transmission lines radiating from this point are all for 25 000 volts, the high-tension switches operate quickly enough that they can be used for synchronizing.

This same arrangement has been followed in the new Springdale Plant in that the main use of the 11 000 volt bus is to synchronize the generators and to supply power to the auxiliaries. In case of emergency, power can be transmitted from one generator to the transformers of another. Where the 132 000 volt switching system is installed, the time element of closing these switches is too great to permit using them for synchronizing.

The Springdale station is arranged on the unit system, each main generator having its own boilers, auxiliaries, transformers and bus sections; thus each unit may be operated to full capacity entirely independent from every other unit. However, the boilers will ordi-

narily supply steam to a common header, and the main units may be paralleled through reactors on the 11 000 volt bus, or directly without reactors on the 25 000 volt bus. Power is generated at 11 000 volts, and space has been provided for duplicate 11 000 volt busses, although only one bus has been installed. This bus and the main switches are on the switch floor and, as may be noted from the main wiring diagram, there are switches to connect each generator and each transformer bank to the bus and to parallel the two sections of the bus through reactors. An auxiliary switch located under the main bus connects each generator directly to its bank of transformers, so if the main bus or any of the oil switches or other equipment on the main bus floor should fail, or if it is necessary to work on them, the service may be maintained by connecting the transformers to the generators through the auxiliary switch and disconnecting the main switching gear by opening the disconnecting switches.

The generator voltage is stepped up from 11 000 to 25 000, at which voltage power is transmitted from the

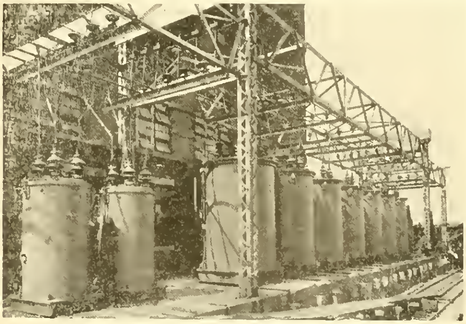


FIG. 16—OUTDOOR TRANSFORMER STATION AT SPRINGDALE
Including seven 8333 kv-a, 11 000 to 25 000 volt transformers, the spare being located in the middle; and four 1000 kv-a, 11 000 to 2300 volt station transformers connected in open delta.

station. There are two 25 000 volt busses, designated as the "Main Bus" and "Transfer Bus". Each of the transmission lines is connected through an automatic oil switch to the main bus and through disconnecting switches to the transfer bus. Space is provided for installing oil switches later to connect to the transfer bus, if operating experience indicates that they are necessary. Each transformer bank is connected to the main bus through an oil switch, which is non-automatic, except through differential relays on the transformers. Each of the two sections of the transfer bus is connected through an automatic oil switch to a transformer bank. A line switch can be taken out of service without an interruption by closing the line disconnecting switches to the transfer bus, and the automatic oil switch connecting the transfer bus to the transformers, before the line switch is opened. The oil switch connecting the transformers to the transfer bus will then serve as overload protection for the transmission line which is operating from the transfer bus. If so desired, all lines may be transferred to the transfer bus and the main bus disconnected entirely without interrupting service.

The voltage is stepped down from 11 000 to 2300 to supply the station auxiliaries. There are two 2300 volt busses, and each circuit is connected to either bus through an automatic oil switch. Each bus may be supplied from the house generator or from either of the two banks of house transformers, and each circuit may thus be supplied from any or all of the three sources. Ordinarily, these busses will not be operated in parallel. The circuit switches are interlocked so that it is impossible to close any circuit onto both busses at the same time unless the bus tie switch, which is controlled from the operating room, is closed. Wherever auxiliaries

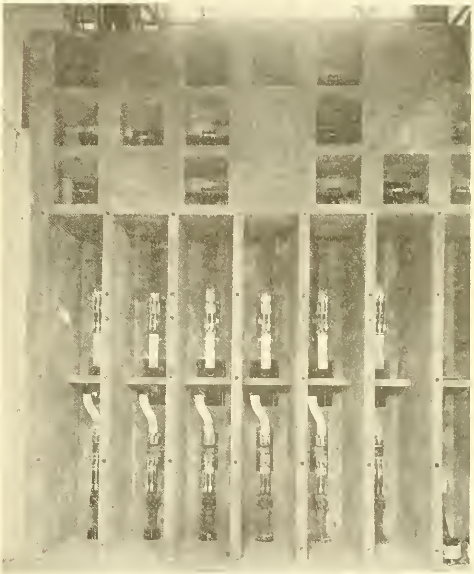


FIG. 17—DISCONNECTING SWITCHES FOR SECTIONALIZING THE 11 000 VOLT BUS

are in duplicate, one will be connected to the house generator and the other to the house transformers, so that half of the auxiliaries will remain in operation, if either source of power is interrupted. Duplicate 2300 volt circuits for the boiler auxiliaries are taken to a group switch center in the middle of the firing aisle, where the stoker, forced-draft and induced-draft motors are controlled, and where they may be transferred from one 2300 volt bus to the other. In a similar manner circuits are run from the 2300 volt busses to group centers in the condenser pit, where the turbine auxiliaries are controlled. In addition to the advantage of reliability obtained from the duplicate circuits and apparatus, and from the two sources of supply, this arrangement permits the regulation of the heat balance by transferring load from the house turbine to the house transformers

or vice versa. The transfer of load may be controlled from the operating rooms or group center.

The two 25 000 kv-a generators are rated at 11 000 volts and have a reactance of ten percent. The generators are star connected, with the neutral of each generator connected to a neutral bus through an oil switch and the bus is grounded through a resistance of four ohms. The generators are protected by balanced relays. The two neutral oil switches are electrically interlocked so that only one generator may be grounded at a time.

Each generator is cooled by washed air supplied by a separate fan, the air washer and fan being in the generator foundation. This air is taken either from the

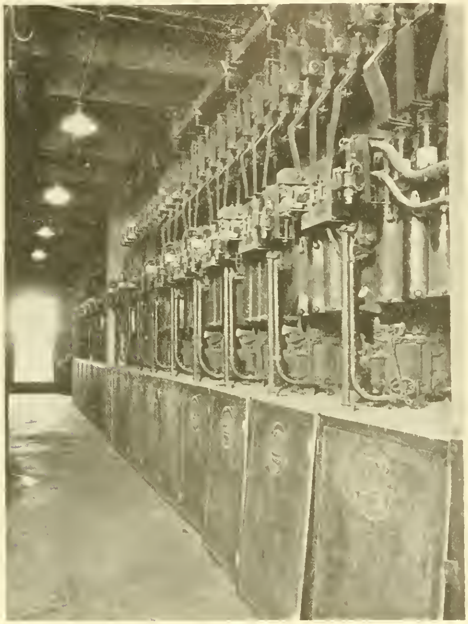


FIG. 18—ONE SIDE OF 2300 VOLT STATION BUS STRUCTURE
All switches are in duplicate.

condenser pit or from the outside and discharged from the bottom of the generators into the intake to the forced-draft fans, or can be recirculated to warm the turbine room to prevent condensation. The house generator is rated at 2500 kv-a, 2300 volts, and is star-connected, with the neutral connected without resistance to ground through an oil switch.

The armature of each generator has six temperature coils embedded in it for indicating temperature on the generator switchboard panels. These temperature coils are embedded in the middle of the slot between the top and bottom conductors and operate ammeters through variation in resistance of the coils caused by change in temperature. Each of the main generators will be provided with steam piping, so that a fire in the generator may be smothered by blowing live steam into the ventilating passages.

Load indicators are being installed to indicate automatically the total station load at all times at four points remote from the operating room, namely:—

1—Station superintendent's office
2—District load dispatcher's office
3—Turbine room
4—Boiler room

These four instruments will all be controlled in parallel by a contact sliding on a resistance unit, the contact being moved by the shaft, which operates the pen on a totalizing graphic wattmeter. The scheme is based on the principle of operation of a potentiometer, the indicators at the remote points being actuated to move so as to balance the current according to the position of the sliding contact on the graphic wattmeter. Each distant meter must take a certain definite position to correspond with each position of the pointer on the totalizing graphic wattmeter.

The leads from the generators are run in an open bus structure and supported on 25 000 volt insulators. This eliminates the cable between the generators and the low-tension bus, with the attendant possibility of shut down resulting from cable troubles, and permits of ready inspection. The floor between the turbine room and the switch room forms a conduit gallery, all the control cables being fastened to the steel floor of the switch room. The controls run between the top of the busses and the floor and the cross controls run longitudinally under the steel floor beams. In this way, the junction boxes not only give access to the control cables, but also serve as the vertical connecting link between the longitudinal and cross control conduit. A storage battery is provided to supply current for the switch controls and for emergency station lighting.

The Windsor Station has a main ring 11 000 volt bus into which the four generators normally feed power with reactors rated at five percent at 30 000 kv-a, installed between units. There is also a reserve 11 000 volt bus to which any generator or feeder may be transferred. The 11 000 volt circuit breakers are installed in concrete cells. Feeder reactors rated at three percent at 80 kv-a are used in the feeder circuits which supply local loads near the plant. Two of the four generators are rated at 30 000 kw at unity power-factor and the generator field is the limiting feature on the output of these machines. The other two units, which were installed later, have slightly higher capacity fields and are rated at 30 000 kilowatts at 90 percent power-factor. Each main unit has a 210 kilowatt, 250 volt direct-connected exciter which may feed current either to its own generator field or to a common exciter bus. The exciter for each unit has capacity sufficient to supply 50 percent more than the excitation for its own unit and can feed current into the excitation bus, which may also be supplied from a 150 kilowatt exciter motor-generator set. The station electrical auxiliaries are driven by 600 volt motors, which are supplied from 1800 kv-a

three-phase, station transformers, which reduce the voltage from 11 000 to 600. The various stokers and overhead cranes are supplied at 600 volts direct-current through two 750 kilowatt motor-generator sets, driven by 600 volt alternating-current motors. A third similar set is being installed to supply 600 volt direct-current to the mine, which supplies the plant with coal and to the Wheeling Traction Company, which is an affiliated company, operating street railways in Wheeling, and from Wheeling to Steubenville. The generators are star-connected, with neutral connected to ground without resistance, the neutral switches being interlocked so that not more than one neutral can be grounded at one time. Each main unit is protected against internal failure by means of balanced current relays, and has no protection against external short-circuit or overload.

A fifth generator, which is a duplicate of the four existing units, is now being installed to be operated as a synchronous condenser, the steam end of this unit being kept in reserve for use for repairs on the four operating turbines. Since the field is a limiting feature on the load which may be placed on these units, it will be possible to obtain materially more kilowatt load from them by improving the power-factor through absorbing a considerable portion of the wattless current by the condenser.

SUMMARY

The outstanding features of the more recent installations of the West Penn System are:—

The location of the two latest stations at the mine mouth, thus making available a reliable source of coal of a uniform grade, with resultant freedom from dependence on transportation systems.

The provision for ample coal storage and for ash disposal on the power house properties.

The reduction to a minimum of the labor required for the handling coal and ashes.

The use of motor drive for auxiliaries, thus reducing maintenance and simplifying the station construction.

The provision of duplicate auxiliaries and sources of power, thus eliminating to a great extent shut-downs resulting from troubles with the small equipment.

The provision of clean water for service use and of distilled water for boiler use.

The handling of air for turbines and boilers in such a way as to prevent condensation and the formation of vapor in the ash pits.

The elimination of excessive air from the feed water, thus reducing corrosion in boilers as well as in the economizers, if the latter are installed later.

Cranes or trolleys have been installed over practically all auxiliaries to reduce to a minimum the time of making repairs.

The installation of the highest capacity switching equipment obtainable. The switches for the electrical equipment were especially designed to give large rupturing capacity and provisions are made to cut out any switch in case of accident or for inspection. The doors for the oil switches and disconnecting switches are interlocked to prevent an attendant from working on any circuit which is in service.

The rendering at all times of continuous and satisfactory service to the customer has been kept continually in mind in designing all details, beginning with the mining of coal and ending with the delivery of power to the consumer.

The future extensions planned are large enough to take care of the customers' increased demands and new business for several years, as the present generating stations are planned for ultimate capacity of at least 500 000 kilowatts.

The Industrial Field of the West Penn Power Company

G. H. GADSBY
Vice-President
West Penn Power Company.

THE WEST PENN POWER COMPANY and electric companies affiliated with it serve a territory of approximately 5000 square miles lying in the counties of Butler, Clarion, Armstrong, Westmoreland, Fayette, Allegheny, Washington and Greene in Pennsylvania, and the counties of Hancock and Brooke in West Virginia. With the exeception of Allegheny and the northern half of Clarion county, the chartered territory comprises all or the greater part of each of the counties enumerated. This area may all be called the Greater Pittsburgh District, justly renowned as the Workshop of the world, or as it is coming to be known, as the Electrical Workshop of the World. Richly endowed by nature with underlying strata of coal, fire clays, limestone, glass sands, silica and quartz rock, and with mountains of stone suitable for paving block and ballast rock, the entire district is the scene of great industrial development. The basic character of these resources contributes to the stability of the enterprises which have been founded and the ready supply of finished and semi-finished materials which enter into the production of important articles of commerce has attracted many industries; and the development thus far has been but a good beginning.

The proximity of the greatest markets in the United States and excellent transportation facilities are additional factors contributing to the importance of this territory and its desirability as a location for manufacturing plants of wide diversity. A glance at the map accompanying the group of articles concerning the West Penn Power Company will show the exceptional transportation facilities. The northern part of the territory, is adequately provided for by the Bessemer & Lake Erie, Baltimore & Ohio, Buffalo, Rochester and Pittsburgh, and Pennsylvania Railroads and is also served by the Allegheny River, which has already been made navigable by the construction of government dams for a distance of approximately twenty miles above Pittsburgh. By dams now under construction or which will shortly be begun, the river will be canalized as far as Kittanning. The main line of the Pennsylvania Railroad runs through the territory immediately east of Pittsburgh on a line through Irwin, Jeannette, Greensburg and Latrobe. The southeastern section is provided for by the main lines of the Baltimore & Ohio Railroad, the Pittsburgh & Lake Erie and the Western Maryland Railroad, following the Monongahela and Youghiogheny Rivers. The southern section, in addition to its railroads, has available water transportation on the Monongahela River, which has been canalized to a considerable distance south of the Pennsylvania—West Virginia state line. The southwestern section is just being developed and, as this development progresses, the railroads are being extended. The central part of Washington County is provided for by the main line of the Baltimore & Ohio Railroad west and the northern part of this county is served by the main line of the Pennsylvania System to Columbus, Cincinnati, Indianapolis and St. Louis. The Ohio River is navigable for its entire length and during the past year there has been a marked resumption of river traffic.

Practically the entire area above defined, which will be referred to as the West Penn Territory, is underlaid with one or more veins of bituminous coal. In the order of their outcropping from north to south are found the following seams:—

Lower Kittanning
Upper Kittanning
Lower Freeport
Upper Freeport
Pittsburgh
Sewickley
Waynesburg

The high quality of much of this coal for use in by-product coke plants opens a vista of development along lines which have just begun to be exploited. It is expected that before many years, with this rich supply of raw material, this district will take its place as one of the leading sections producing the wide variety of commercial products for which the materials from the by-product coke plant form the base.

Except for the territorial lines, it is not possible to separate the individual central station companies in the Greater Pittsburgh District. The marked economic saving by interconnecting large central stations made possible by the standardization of 60 cycle generation was early appreciated and through numerous interconnections of considerable capacity and the co-ownership of one large plant, the central station service of the entire southwestern part of Pennsylvania, Panhandle of West Virginia, and eastern Ohio have literally been welded into one solid electrical block.

A description of the three large stations of West Penn Power Company and its network of transmission lines is contained in accompanying articles in this issue of the JOURNAL. The arrangement of these stations in relation to each other is noteworthy, forming a great triangle in the center of the territory served. The prospective hydro-electric development on the Cheat River, could scarcely have been placed in a better location for the future development of the southern part of the West Penn territory, just beginning to be opened.

An industrial survey made a few years ago would have shown the large manufacturing plants and industrial cities located along the banks of the rivers and at places where a fuel supply could readily be had or large fuel storage provided. With the development of central power station service, the necessity for considering individual power plant requirements when locating factories has disappeared. The development of factories on a larger scale is possible by reason of the fact that capital investment for power plants is no longer necessary for factory owners. Emphasis should be laid upon this point because it will frequently be found that the investment by the central station to serve a given factory is greater than the investment in the factory itself. The company desiring to locate and build a manufacturing plant is now able to start that plant on less capital or put in a much more economical or extensive plant on the same capital in territory having adequate central station power service. This lessened capital investment makes easier the financing of new enterprises or extensions to present plants, and at the same time decreases the risk in possible loss should the project fail to earn its way.

The West Penn Power Company is essentially a *power* company. While it does serve the domestic, commercial and municipal requirements of practically all of the towns and cities in its territory, the total capacity and total amount of energy delivered for these purposes is exceeded by the capacity and energy delivered and used for industrial power and heating. The diversity in the requirements of the different consumers is a big factor in rate making, and the fact that there is such wide diversity among the consumers of the West Penn Power Company has enabled it to maintain rates for service quite comparable with those of large power stations serving entirely congested city districts where the density of load is several times that existing in the comparatively open country which comprises such a large part of West Penn territory.

With something over 50 000 customers, power users constitute scarcely five percent of the total number.

Without taking into account the power service supplied to its affiliated railway companies, 75 percent of the total energy generated in all the plants of the West Penn Companies goes to this five percent comprising its industrial users. It is estimated that the population in the territory served by existing lines is over 550 000. The total number of towns and communities in which service was being supplied on December 31st, 1920 was 324, of which 126 have a population of 1000 or over.

The West Penn Power Company does not sell wholesale energy for domestic and commercial purposes but is organized to take care of the entire process of sale to the smallest ultimate consumer. This is accomplished by the division of the territory into a number of districts, each district centering about one of the largest towns located therein. Each district is under the direction of a local superintendent, with a well organized office and field force, so that it is possible to give prompt and efficient service and to maintain the quality of service at a high standard.

The increasing use of central station power by new industries and through the replacement of other sources of power supply is clearly shown by the growth of the generating capacity installed in the stations of the West Penn System. The following are approximate figures, based upon name plate ratings of the generators in all of the stations in service:—

1905	6.000 kw
1910	12500 kw
1915	51500 kw
1920	138000 kw

The growth in the load carried by these stations has increased in like proportion, while the operating load factor of the stations has improved from year to year, meaning a corresponding increase in the total output of energy. Great strides have been made in the design of large generators so that the efficiencies obtained from the new stations with their large units are in marked contrast to those secured from the small units of the earlier period of the Company's history and also to the small units or steam engines in the few remaining isolated plants in the territory today.

Approximately 50 percent of the power supplied by the West Penn Power Company is used for mining coal. Service is supplied to more than 400 mines and is utilized for all power purposes incident to coal mining. Some mines are supplied throughout with West Penn power; others have mixed drives with the tendency towards taking all the service from the Power Company's lines. The principal operations in coal mining requiring the use of power are,—the operation of ventilating fans, pumping in conjunction with the mine drainage systems, electric locomotives drawing the mine cars from the rooms and entries to the foot of the shaft, hoisting (either incline or vertical lift), coal cutting and loading (the latter being a comparatively recent development), the operation of washers and crushers where prepared coal is shipped, and incidental uses, such as lighting, operation of machinery in the repair or construction shops, miscellaneous loading equipment, and other smaller power uses incident to the auxiliary operations about the mine. The mining loads vary from a few kilowatts for cutters in the small mine working in the outcrop to huge hoists requiring motors as large as 1500hp. The load factor of the mines, depends entirely upon the power required, the mines having comparatively heavy ventilating and pumping requirements operate at very high load factors, while those having natural drainage in non-gaseous fields using power only for cutting, hauling and incidental uses consume power during fewer hours of the day. An average of all mining operations would show a load factor of 25 to 30 percent.

While an immense amount of coal has been taken out of the local fields, there are great acreages yet untouched, particularly in the southwestern part of the territory, and it now appears that most of this coal will be developed by large companies operating completely electrified mines of from one to ten thousand tons daily capacity.

From the standpoint of station demand and energy consumed, the electric steel companies rank next to the coal mines. This includes both electric furnace plants and rolling mills. There is no more interesting story than that of the electric melting furnace. Definite temperature control and the ability to make high grade steels from cheap scrap have placed the electric furnace in a field of its own. Furnaces now on the West Penn System range in capacity from small 100 kw special alloy furnaces to ten ton furnaces making castings of special grades, and sheet and bar steel. While the cycle of operation of a steel furnace is such that there is considerable variation in the power requirements of a single furnace, the continuous use and custom of having several furnaces supplied from one service connection, makes it possible for the steel furnace to create a very good load factor. It is a mooted question whether an electric furnace can compete with other types of furnaces in the production of ordinary commercial steels. It is a safe assertion, however, that an electric furnace is superior for making alloy and tool steels. There are at least ten plants on West Penn lines operating electric steel furnaces. These produce not only steel but ferro-alloys, for which there is a ready market among steel companies all over the country. The following alloy steels and ferro-alloys are made in these plants:—

Vanadium
Molybdenum
Tungsten
Chromium
Cerium

and some special combination alloys made for specific purposes. This district is the largest producer in the world, of some of these alloys notably those of cerium.

The rolling mills are coming to realize the possible economy in the use of purchased central station power. The West Penn Companies now supply practically the entire requirements of three plants with demands as high as 5000 kw in a single plant, and a large number

of partial installations. The perfection of the gear drive was a long step forward in the use of electrically-driven rolls with sixty cycle power service. The use of motors of twelve to fifteen hundred horse-power is by no means unusual. The plants served produce bars, sheet and shaped steel, corrugated and galvanized sheets, and tin plate.

A comparatively recent innovation is the use of purchased electric service for annealing furnaces. The development along this line is progressing and it is believed that the day is not far distant when the heating load, consisting of the high temperature electric furnace and lower temperature annealing and pre-heating furnaces, will rival the motor load both in capacity required and energy consumed.

In point of demand the power required for street railways, both affiliated and those of other companies, is next in importance. Practically every electric street and interurban car in the West Penn territory is operated by West Penn power.

The glass industry takes the next largest block, there being eighteen companies supplied with an ever-increasing demand. This is a most desirable load for the central station because of high load factor in the operation. The Pittsburgh district, originally on account of the fine sand available and the supply of natural gas, has developed some of the largest glass plants in existence. Research work is being done on an electric glass furnace, made necessary by reason of the rapidly diminishing supply of natural gas. An increasing load is anticipated in this field.

An arrangement of industries according to their aggregate demand on the central station is not possible, but as correct an analysis as is possible would indicate that the foundry and machine shop business is next in importance, closely followed by a large number of brick plants turning out an excellent quality of refractory, fire and building brick. By reason of the high quality of the clays and shale rock, the product from these plants finds a ready market and is shipped to all parts of the world.

A scarcely less important group is the pottery and clay products industry. The plants in this district manufacture not only the customary line of china and earthen ware goods but there are some plants highly specialized in character making products tributary to the other major industries of the district, such as special pots for glass melting. What is reputed to be one of the largest pottery plants in the world is located in the northern end of the West Virginia Panhandle and is largely supplied with West Penn service.

One of the large aluminum plants is located in this territory and is partially supplied with purchased power. There are a few chemical companies, three radiator works, seven steel fabricating or steel construction plants, one large cast iron pipe mill, several rubber plants, and a large number of smaller plants making all variety of products.

Contributory to these larger plants and to the population brought to the district by reason of these mining and manufacturing interests are a large number of laundries, ice cream companies, bottling works, packing houses, printing shops, water works, by far the greater part of which purchase their power supply.

The best prospectus of any territory is a review of what has already been accomplished. The wide diversity of successful enterprises in this district is the best advertisement of the district for attracting new plants. One of the large Pittsburgh banking institutions recently made a careful survey of the resources and facilities afforded in this district for specific lines of industry. Taking into account the basic products above enumerated and remembering the excellent transportation facilities afforded to the nearby markets, this district offers special inducements for certain lines. Thus:—

It is reported that out of 100 chain plants in the United States there are three in the Pittsburgh district. When it is considered that an immense tonnage of rods is produced here, shipped elsewhere and manufactured into chain, then returned and used in this immediate locality, it is at once apparent that this is the logical location for plants of this character.

Metal lath is being used in increasing quantity as the cheap lumber supply is disappearing and the superior quality of metal lath is realized. Out of forty metal lath plants four are located in the Pittsburgh district.

Steel lumber, consisting of strip steel shaped with an angle or channel on one edge, was first made in 1906 and will increase in use in the future.

The maker of show and display cases will find an excellent supply of the materials required made close at hand. There are three such plants now in this district out of 170 in the United States.

Metal ceiling were first made in Pittsburgh and have since come to be used extensively. There is but one such plant here out of fifty in this country.

Wire rope should most profitably be made here with the large number of wire mills close at hand, but there is now only one out of forty of such plants.

Cans and tin food containers, talcum boxes, tobacco tins, and like articles can be well be made here, although there are now but three out of one hundred such plants.

Fire arms are made essentially of steel. The growth of plants of this character has been a matter of custom and precedent rather than availability of the raw materials, so that we now find that out of twenty-seven plants in the country none are in Pittsburgh.

Surgical instruments are also a steel product and there is but one plant out of three hundred. There is one plant manufacturing scales and balances out of 130; one making refrigerators out of 140; no printing press plants, although there are 88 in the country requiring large steel castings and metal parts of all kinds.

With the realization that better goods can be made in this county than abroad, the demand for domestic-made toys, into which small metal parts enter so largely, will be a growing industry in the United States and the proportion of eight plants to four hundred will, without doubt, soon be materially increased.

The construction of steel river craft will resume increasing importance with the resumption of water transportation and facilities afforded for plant sites, materials required, and power supply cannot be excelled any place else in the country.

Aeroplane factories will soon be found scattered over the country as automobile factories are today. The Pittsburgh district again offers the raw materials and may be expected to have a large share of these plants.

The manufacture of metal office and house furniture and house trims is resuming increasing importance and here again the logical location for such plants is in this district.

The use of small tractors is replacing the horse-drawn equipment on the farm, by the contractor, and for the moving of heavy loads even considerable distances. There is one plant here producing small tractors out of 161 plants in the United States and an increase in this type of factory is anticipated.

As has been pointed out, the development of central station power has vastly extended the area available for plant and factory sites. Reference to the map of the existing transmission system shows that about 50 percent of the West Penn Power Company territory is now supplied with power service. This coincides closely with the portion of the territory which is under active industrial development. The extension of power lines follows closely the beginning of development and in many cases is the first step towards the opening of new sections of country. The table above containing the statement of installed capacity in the power stations shows the rapid rate of development and is an indication of what may be expected in the future.

State regulation has removed the speculative feature in utility financing and placed it upon a sane, conservative, substantial basis. Recent experience of the West Penn Company has demonstrated that adequate, reliable service is recompensed not only by a ready market for its services but by a spirit of co-operation in the communities served when it comes to financing the requirements of the Company. It is believed, therefore, that the growth of the central station companies will keep pace with the industrial requirements and that the patrons, present and prospective, will do their part in the necessary financing of the enlargements and extensions required. The growth of the electric industry itself is well known and each year is producing equipment and devices designed to improve the quality of service, both in its continuity and uniformity of character. At the same time the manufacturers of electric utilization equipment are constantly producing new and more efficient apparatus.

The plans of the West Penn Power Company are comprehensive and look forward several years in the future. The present stations at Springdale and Windsor are constructed with enlargements in view and it is expected that these enlargements will come forward with regularity and according to a fairly definite program based upon the increased requirements for service as demonstrated by past experience. The development of the water powers in West Virginia will add a large block of capacity. The transmission systems both of this Company and its neighbors are laid out with the idea of making service flexible and interchangeable, which means a greater possible power output for a given amount of investment and an increased insurance of uninterrupted service from the many large plants well scattered over the territory supplied.

The projected line extensions into the northern part of the territory will open new country, increasing the production of plants now in operation and making possible the location of many new industries on most desirable sites close to the raw materials they require.

The power company's function is to sell service and the managers of central stations have come to realize that its successful operation depends upon service. The result is an increasing co-operation between the producer and the user of power with the mutual development of the central station company and the territory it serves.

The Power Stations of the Duquesne Light Company

J. M. GRAVES
Asst. General Manager
Duquesne Light Company

An interesting transformation is taking place in the power generating system of the Duquesne Light Company. Only a few years ago ten power stations constituted the generating system, some of these producing both steam and electricity for sale. Some were considerably isolated, some notoriously inefficient and others of distinctive characteristics.

A period of concentration of attention on the Brunot's Island station then started, but with the other plants maintained in the best of repair and operating condition. Now that the new Colfax Station is a reality, all attention to power generation centers about this and Brunot Island, and the small stations are little used, so far as power generation is concerned. In contemplation of this change, an entirely new system of station management has been put into effect at the large stations, but there is no attempt to do so at the small ones. A map showing the location of these plants in relation to the centers of population in and around Pittsburgh, is shown in Mr. Stone's article in this issue.

BRUNOT ISLAND

The inherent difference between the Colfax and Brunot Island stations lies in the fact that the latter is made up of a collection of relatively small generating units, both boilers and generators, while Colfax, having much larger units, will not attain the same percentage of flexibility until it has possibly three times the installed capacity of the other station. The boiler room of the Brunot Island plant includes interesting examples of what was considered the highest attainment in boiler construction at the time various units were installed. The original plant consisted simply of a building separated by a wall in the middle with a row of boilers on one side and a row of engines on the other.

All apparatus of importance was located on one elevation, namely the main floor, and the matter of height and depth did not seriously enter into the station design. Thus the original boilers were 500 rated horse-power three drum construction with two stokers per boiler. They were installed separately, with two boilers connecting into a seven foot steel stack 130 feet high. No superheaters were installed and 10 in. steam leads from each boiler connected to an 18 in. header along the turbine room wall. Coal was supplied by a larry running along the floor in front of the stokers, and ash removal was taken care of in a relatively small cellar under the main firing aisle. These same boilers are operating today, and with the addition of superheaters, smaller size non-return valves, overhead coal supply, undergrate blowers and firing instruments they are performing very satisfactorily.

As the demand for more steam became imperative 600 hp boilers with Roney type stokers were installed in an addition made to the original building and operated for a number of years, when they were raised and equipped with improved underfeed stokers. These also are operating at the present time at an average rating of about 190 percent normal and, considering the improvements made in furnace design, they constitute a very satisfactory unit. These boilers are also served by steel stacks 175 ft. high, two boilers per stack. The remainder of the boilers in this row are 822 hp equipped with underfeed stokers. All of these are supplied with forced draft and, for this purpose, nine fans are used to serve 18 boilers, the fans discharging into a common air duct. Six of these are electrically driven by 125 hp variable speed induction motors, and are hand controlled through four ranges of speed. The remaining three are driven at the same speed by turbines through reduction gears, and are regulated by hand throttle control only. As the fans operate most efficiently when running at the same speeds, effort is made to either vary their speeds altogether or cut out fan units entirely according to changes in load.

When the demand for more steam came the chain grate stoker was enjoying an era of popularity, and accordingly a new addition of twenty 822 hp boilers with chain grate stokers were installed. The boilers were installed in batteries of five at right angles to the original boiler room and served by brick stacks 208 ft. high for each two batteries of boilers. This made a boiler plant covering a considerable area. In fact 83 000 sq. ft. of floor space was covered by 37 700 normal rated horse-power, or 0.45 hp per square foot. An interesting comparison can be had with the Colfax boiler room in which 29 250 normal rated horse-power are developed on 36 800 sq. ft. of boiler room floor space, or 0.8 hp per square foot.

FIG. 1—BRUNOT ISLAND POWER STATION

The steam piping in a boiler room of this size naturally became an exceedingly important feature.

Since all of the new boilers had been equipped with superheaters, delivering steam at 500 degrees temperature and 200 lbs. pressure, this phase of development somewhat outgrew the application of metals to steam pipe fittings and valves. Certain accidents in the failure of fittings in other plants and in our own proved beyond a doubt that the general use of highest grade steel for valves and fittings was necessary. Action along this line was immediately started, and at the present time a great part of the steam piping is equipped with all steel valves and fittings, and to a considerable extent the valves are motor operated. Motor operation of valves also presents a unique matter of judgment as to what purpose the valve motors should serve primarily, and from what location they should be controlled. The belief prevails that the motor operation of these valves is desirable from the standpoint of normal, as well as abnormal operation, and additions to this equipment are being made at the present time carrying out this idea.

In the new addition, the boilers were originally equipped with coal scales for each boiler, but in the course of time the use of these was abandoned. Each boiler is also equipped with a flow meter, CO_2 recorders, and combination inclined tube draft gages. The underfeed boilers are equipped with boiler meters having steam and air flow and draft indicators. The smaller boilers are being equipped with CO_2 recorders for trial.

The important feature of coal handling at this station is a 100 000 ton coal basin built so as to be filled with water from the condenser discharge and drained into the river at will. Coal is received both by rail and river and weighed into the plant.

TURBINE ROOM

This is one of those plants which developed to its present capacity, rather than one that was so built. A small 3000 kw unit and a 40 000 kw compound unit break the monotony of the other 15 300 kw units. There is a fair degree of uniformity of arrangement of auxiliaries throughout the condenser cellar, considering the changes the plant has undergone, but this necessitated a rather complicated layout of piping which is being simplified as conditions permit.

It is interesting to note the contrast in the exciter units of this station with those of the Colfax Station, due to the fact that where continual development is taking place all system and order of arrangement is obliterated. Exciters are placed where floor space best permits. The controlling factor as to whether they are steam or electric driven is a variable, depending on prevailing ideas at the time when more exciting current was needed, and there was no precedent to prevent the installation of whatever machine seemed most reliable. The majority of the auxiliary apparatus is steam driven and the quantity of exhaust steam available is such as to provide an excess in summer just about equal to the deficit in winter. This is utilized in open feed water heaters where, up to the present time, no definite arrangement has been put into operation whereby the station heat balance is entirely under control. This is being done by the replacement of some steam driven auxiliaries with motor drive, and bleeding steam automatically from the intermediate of the compound unit to maintain the feed water at 212 degrees F.

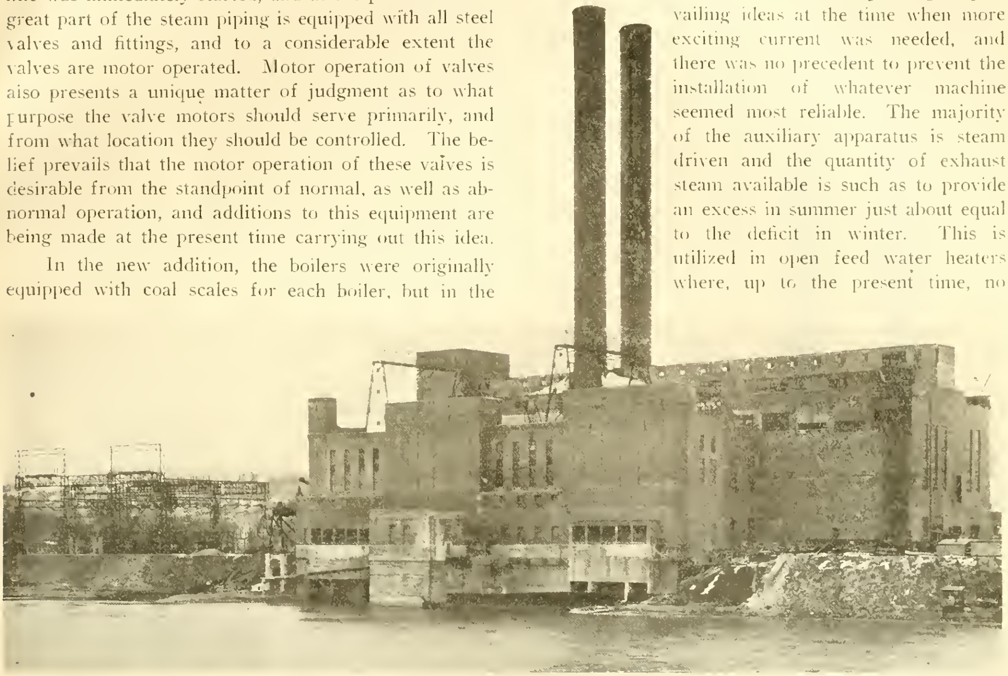


FIG. 2—COLFAX POWER STATION FROM RIVER

This station, although apparently isolated on an island, is really in the midst of Pittsburgh's busiest manufacturing district, which accounts for the fact that a large number of feeders proceed from the station. This means a somewhat complicated switching equipment and a feeder board that requires much attention. The operating gallery for this board is on a balcony projecting out into the turbine-room in such manner as to command a good view of the entire floor.

Station service to coal handling machinery is through rotary converters which tie in with the city street car circuits. A 250 volt battery is maintained for excitation and lighting emergency, and in general every-

thing possible has been done to insure continuity of service in this station*.

THE COLFAX POWER STATION

The present and ultimate layout of the Colfax Station, is shown in Fig. 4, the heavy outline showing the portion already constructed. The principal equipment in the present building consists of seven boilers, one three-element 60 000 kw main generating unit, three feed pumps, one evaporator, one house turbine, one heat balance motor-generator set, two stoker motor-generator sets two exciters, one bank of main transformers and the necessary oil switches and auxiliaries. There will be one screen house and one main feed water storage tank for each two main units. There is a stack for each four boilers.

It will be seen from the cross section of the plant Fig. 5 that the main three-phase high-tension busses are simply heavy cables located over the turbine room, and that the addition of main units does not involve the changing of feeder circuits. The plant is designed to operate on the minimum of man power and includes as many automatic features as modern power station design seems to justify.

In this station we have a power station within a power station, as far as prime movers and electrical equipment is concerned, the boiler plant being common to both. That is to say, a house turbine drives a generator on a separate bus, from which feeders proceed to the various auxiliaries of the main units throughout the plant. Economizers are not used but space is provided in which they can be installed. Surface condensers return the main bulk of the boiler feed back again to the boilers. The water supply in the Allegheny River is contaminated to such an extent that this is not depended on even for make-up without distillation. An evaporator is, therefore, provided for this purpose, which gives a boiler feed of 100 percent purity.

There is complete concentration of various equipment, from the standpoint of boilers, general station auxiliaries, main units, electrical equipment and water supply; that is to say vertical lines drawn through the plant completely isolate these classes of equipment.

STEAM GENERATION

In the design and arrangement of the steam generating equipment for this station, the best modern developments in central station practice are made use of, in a conservative way. Large size units, with ample total capacity, operation at efficient ratings, ease and convenience in operation, inspection and maintenance, are the main points arrived at with this equipment.

The boilers are of the cross-drum type, rated at 2088 boiler horse-power, each with 20 880 sq. ft. of heating surface. The stokers are underfeed, with 17 retorts per boiler. The stoker equipment includes double-roll clinker grinders for the removal of ash. Steam is generated at 275 lbs. gage pressure and 180 degrees superheat is obtained with superheaters.

Seven boilers are installed at present to care for the 60 000 kw turbogenerating unit and steam driven auxiliaries. Seven more will be installed in the near future to care for the second 60 000 kw unit. In normal operation, six boilers are for each unit, with the seventh in reserve.

The boilers are arranged in two rows, along a common firing aisle, parallel to the turbine room. The main steam header is placed at the rear of the row of boilers nearest the turbine room, and five feet above the boiler room floor. The stacks are arranged in pairs, each pair to care for the gases from eight boilers, or four boilers in a row per stack. Two boilers on each side discharge their gases into a common breeching leading to the stack. These are steel lined and self-supporting on the steel framework of the building, 21 ft. inside diameter and 325 ft. high above the boiler room

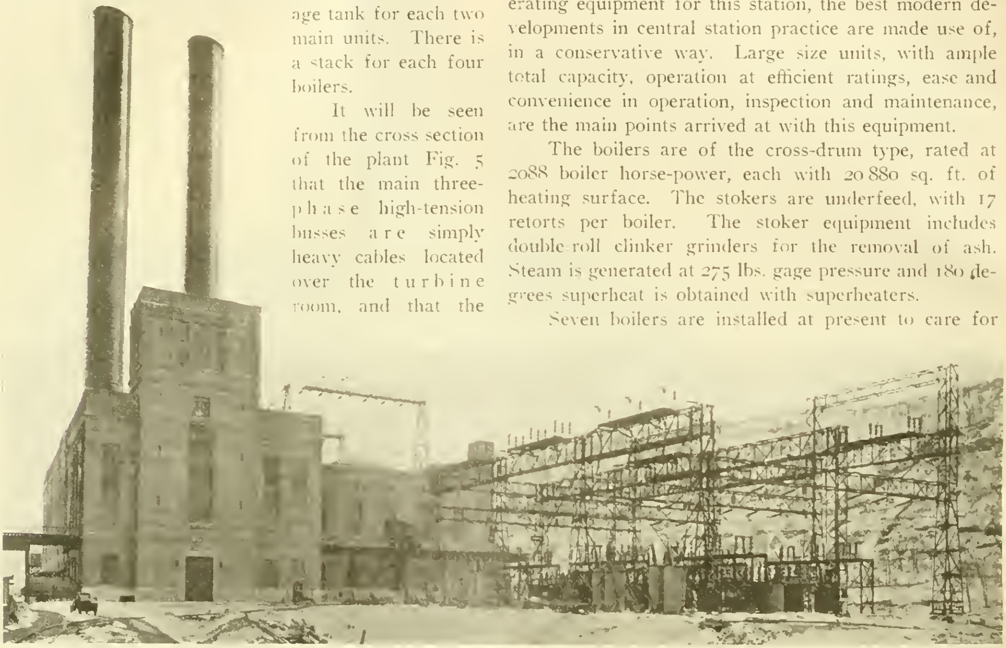


FIG. 3—COLFAX POWER STATION AND OUTDOOR SUBSTATION

*A more complete description of this plant is given in an article on "Brunot Island Power Station" by F. Uhlenhaut, Jr in the JOURNAL for June, '15, p. 241.

floor. Coal is spouted into each stoker hopper from a traveling coal larry with duplex hopper weighing scales. The larry is fed through down spouts from the overhead bunkers. Ashes and refuse fall from the clinker grinders into a concrete pit, brick lined, supported by the steel framework of the building. Underneath each row of boilers is an ash track at the ground level. Each ash pit has three sliding doors, operated by compressed air, through which ashes are dumped directly into gondola cars. Feed water lines are in duplicate. The main feed line runs underneath the boiler room floor from which risers lead upward to each end of drums. The auxiliary feed line runs above the boilers and leads are taken off to each end of drums. The main and auxiliary lines unite just before entering drums.

DIMENSIONS

The overall dimensions of each boiler space are 36 ft. wide and 23 ft. 9 in. deep, center to center of columns. The boiler itself is 34 ft. wide by 22 ft. deep. The height is 35 ft. from floor to center of drum, and the entire height from bottom of ash pit to top of steam lead is 63 ft. The firing aisle is 23 ft. 9 in. wide and the spaces between boilers at sides are 12 ft., center to center of columns.

A distinguishing construction feature is the placing of the drums and uptake at the front of the boiler instead of at the rear. The gases therefore travel from the grate surface toward the rear wall, thence upward through the first pass at the rear of the boiler. This arrangement eliminates the necessity for a heavy wall over the stoker fronts, and tends to keep the hot gases away from the stoker hoppers and air distribution boxes. As a part of this arrangement the tubes slope forward instead of to the rear.

BOILER TUBES

Each boiler has 918 tubes, each 4 in. diameter and 20 ft. long, arranged 51 wide and 18 high. There are also two rows of horizontal circulating tubes from the rear header to the drum. The two lower rows of tubes are not staggered and there is a space of two feet between these and the next row above. These two rows are of No. 7 B. W. G., while the others are of No. 8 B. W. G.; all of hot finished seamless steel.

The two lower rows of tubes are expanded into short and straight headers separate from the regular headers above and connected to them by short nipples. The remaining 16 rows are expanded into vertical headers of the usual serpentine form. By the straight arrangement it is hoped to prevent the formation of slag on the lower rows of tubes, which is always a serious trouble when boilers are operated at high overloads, and especially so with staggered tubes. All headers are provided with hand hole openings, one for each tube end. The spaces between the headers are asbestos packed.

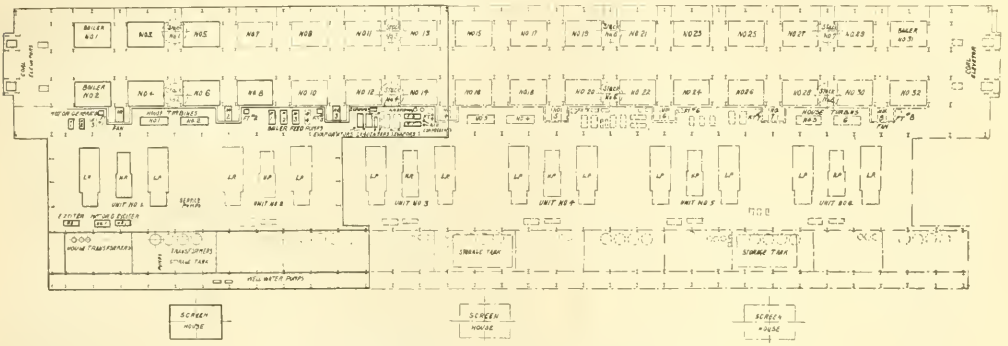


FIG. 4—PRESENT AND ULTIMATE PLANT OF COLFAX STATION

BOILER DRUMS

The drums are 60 in. diameter and 34 ft. long, with shell and heads of 1-1/16 in. and 1⅛ in. plate, respectively. Longitudinal seams are double butt strap joint, triple riveted, and circular seams are lap joint double riveted. A manhole is provided in each end of the drum. Feed water inlets, one at each end, project above the water line and discharge through taper nozzles against hemispherical caps which break up the stream into circular sheets, thus distributing the feed water more evenly over the surface and preventing the formation of currents to interfere with regular circulation. The steam is collected in a dry pipe at the top, extending the full length of drum and is drawn off through two eight inch outlets in the top of the drum. Five connections for safety valves lead from the top of the drum, with ten 4.5 in. safety valves providing ample relieving capacity for any emergency. The steam outlets from the drum lead to the superheater inlets, one at each side of boiler.

SUPERHEATERS

The superheaters are installed in the usual manner between the top row of tubes and the horizontal circulators, and extend in two sections the full width of the boiler. An inlet and outlet for each section is provided, one at each side of boiler. A 4.5 in. safety valve

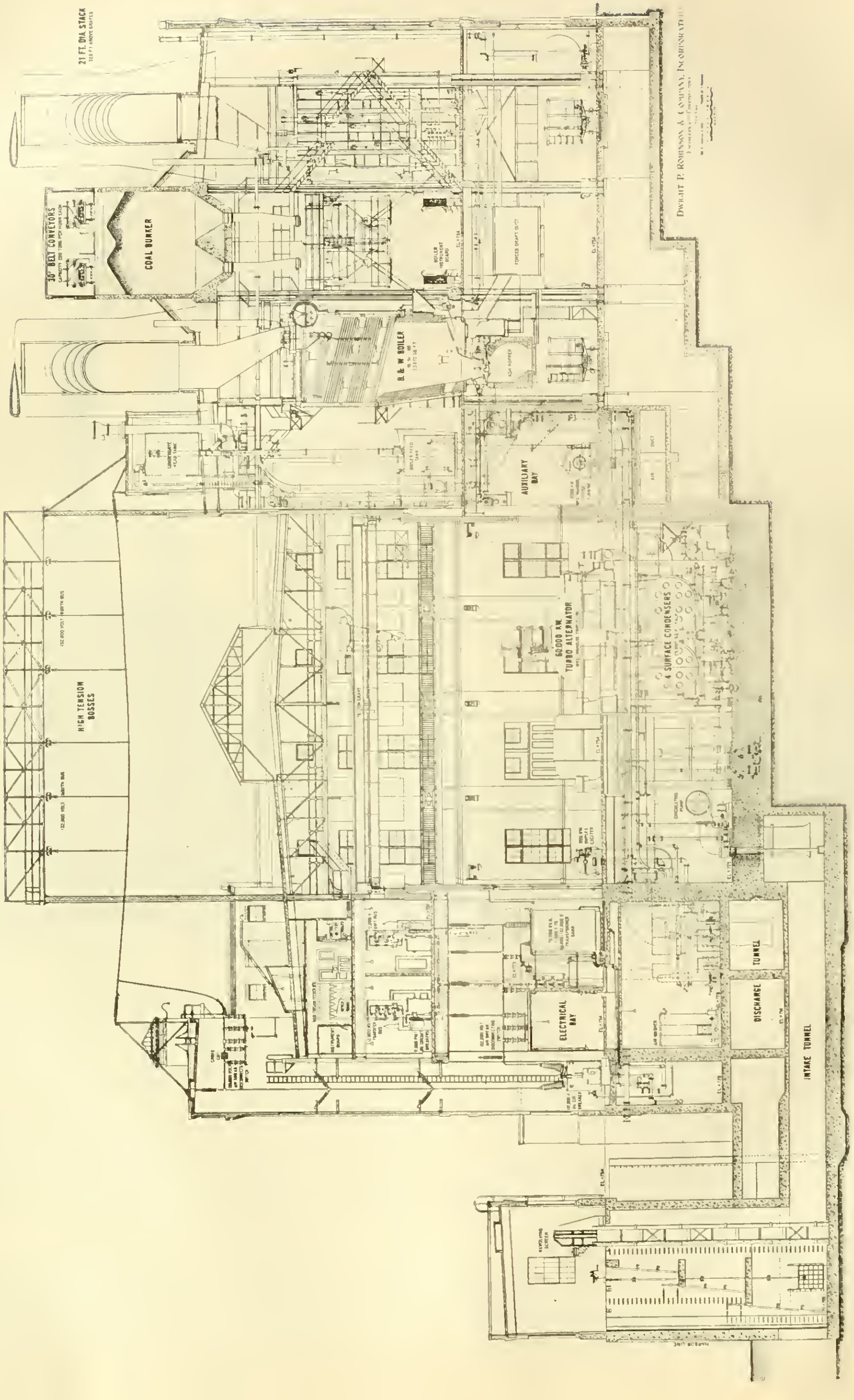


FIG. 5—CROSS-SECTION THROUGH COLFAX PLANT

is installed in each outlet. Each outlet passes into a Y-connection with the corresponding outlet from the boiler of the opposite row, and the two pass through a common lead to the steam header below. A stop valve and non-return valve in each outlet prevent any possibility of reverse steam flow into boilers. The superheating surface is 6765 sq. ft., and the superheat may vary with the output from 130 degrees at rated capacity not to exceed 200 degrees at highest overload. The superheat will be 180 degrees at 200 percent rating.

BLOW-OFF FACILITIES

A mud drum of the usual forged steel box type, 8.25 in. square, extends across the boiler front just below the lowest row of tubes. It has two blow-down connections with blow-off cocks and mud valves. The

FIG. 6—ONE OF THE 2088 HP BOILERS
Showing stoker and stoker gage board in front of the boiler, and soot blowers at the side.

blow-off lines feed into a common header which can be opened either to the river or to a storage tank in the ash cellar, from which the water can be returned to service after settling.

STOKER DRIVES

Each stoker is driven by a 20 hp adjustable speed direct-current motor, set on the boiler room floor at the center of the boiler front, and connected to the stoker crank shaft through silent chain drives and double worm reduction gear boxes. Each of the seven sections are provided with throw off clutches and shearing pins to relieve excessive load. The rams are driven by short connecting rods from the crank shaft. Links on each side of the rams connect to the lower push plates, with a lost motion slide and lock nuts for adjusting the stroke to suit the fuel. The speed ratio of the motor to the crank shaft is approximately 750 to 1, and the speed range of the motor is 250 to 1175 r.p.m. at full load. Each of the 17 stoker rams handles approximately 20 lbs. of coal per stroke. Thus the stoker capacity may be varied from 6800 to 31 900 lbs. of coal per hour with continuous operation. The corresponding ratings are approximately 90 to 450 percent, thus giving extreme flexibility to meet all possible operating conditions.

GRATES AND AIR CONTROL

The grate surface proper is 30 ft. wide by 13.5 ft. long, making a total grate area of approximately 400 sq. ft. Air is admitted through multi-opening tuyeres from the air box underneath the retorts. Cast iron coal extension plates round over from the lower end of the retorts into the clinker grinder pits. The pressure in the air box may be hand controlled by dampers leading from the main air duct. Another set of dampers regulates the air supply to the lower part of grates, while still further dampers control the cooling air supply to the coal extension plates.

CLINKER GRINDERS

The double roll clinker grinders are set in a pit five feet below the lower grate surface, which insures a sufficient depth of ashes to keep the rolls covered at all times. Five cast iron sprinkler heads project 18 in. above the rolls, supplying water continuously for wetting down the ashes and clinker before they reach the rolls. The rear wall of the pit is protected by air cooled cast iron deflector plates and the ends are lined with fire brick. The lower part of both front and rear pit walls consists of a movable apron, pivoted at the top with the lower edge reaching down to the center line of the rolls. These aprons are held in position by arms at the back and have worm and sector adjustment controlled from the boiler room to adjust the distance between the aprons and rolls. The rolls are supported on cast iron bearing blocks bolted to the structural beam at each side of the pit. The roll itself is made up of cast iron split sections each 11 in. diameter and 20 in. long, bolted to a 5 in. square steel shaft. Cast iron stub teeth with countersunk square heads are inserted in the roll sections from the inside before bolting into place. The clinker grinders are in two sections, driven by 10 hp adjustable speed direct-current motors, one at each end, set on the boiler room floor. The driving mechanism consists of silent chain with shearing pins to relieve overload, double worm reduction gear, crank arm, connecting rod, rocker arms, and ratchet wheels on roll shafts. The extreme speed range for the grinder rolls is from 0.6 to 9.6 revolutions per hour.

FURNACE AND TUBE BANKS

The combustion space allowed is unusually large, the lowest row of tubes being 20 ft. above the grates. At the fire line the furnace lining consists of ventilated blocks backed by air spaces supplied with air from the main air duct. Above the fire line, high-grade refractory brick is used. One door in each side wall and

four in the rear wall allow easy access to the furnace for inspection and care of the fire. The horizontal baffle is laid on top of the second row of tubes to protect it from the direct action of the fire. Vertical baffles divide the tube space into three passes, which are proportioned to give proper passage area as the gas becomes cooled. The uptake has an effective area of 135 sq. ft. Double leaf balanced dampers in the uptake control the stack draft. Balanced draft regulators control the position of the dampers automatically so as to maintain the proper draft over the fire under all conditions.

SOOT BLOWERS

Soot blowers are installed for blowing soot from the tubes. Nine elements are arranged in duplex, with steam supplied at each side of boiler and the elements meeting at the center. Steam is taken from the auxiliary steam header. Operation of each element three times per day keeps the tubes clean and free from soot.

BOILER INSTRUMENTS AND INSTRUMENT BOARDS

An instrument board is installed at the front of each boiler, facing the firing aisle. Mounted on this board are the two steam gages, one on each water column; draft gages, showing drafts at the damper, over the fire, and in the air box under the grates; two venturi meters, one on each main feed line; and an automatic CO_2 recorder. At the foot of the board are the drum controllers for the stoker and clinker grinder motors. Pilot lights mounted on the board serve to illuminate the various instruments and to indicate when current is available for the operation of motors. The drafts are automatically regulated to keep the air pressure at the fire the same as in the boiler, to prevent air leakage through the doors. Another large instrument board spans the firing aisle and on it are mounted a clock, a master steam gage, and a station load sign; all with double faces and illuminated dials. These three instruments are thus made visible the entire length of the firing aisle.

BOILER PERFORMANCE

The combined performance of boilers and stokers are as shown in Fig. 8. When each boiler is generating 130 000 pounds of steam per hour, the value of important variables will be as follows:—

Wind box pressure 3.2 inches of water,
Superheat 154 degrees F.,
Speed of stoker shaft 210 r. p. m.,
Amount of air to stoker 5,500 cu. ft. per minute,
Combined boiler and furnace efficiency 77 percent,
Flue gas temperature 470 degrees F.,
Amount of coal burned by each boiler, 5.7 tons per hr
Flue draft-0.7 inches water.

The automatic control of the boilers is accomplished by means of the separate variables:—

1—Pressure differential in fuel bed, and
2—Pressure differential in tube banks.

The first is controlled by steam pressure through the regulators on the forced draft fans, and is the primary variable, i.e., air is supplied to the fuel bed in proportion to the demand for steam, and as secondary operation the stack damper is adjusted by means of the balanced draft apparatus to meet the demand of the fuel bed. The third or independent variable is the rate of feeding coal to the boiler which, of course, does not vary as rapidly as the air supply, and is entirely under the control of the stoker operator. The CO_2 recorder is a valuable guide in the regulation of the air supply.

An exception to the above sequence is had when the damper adjusts itself to a condition of the fuel bed which may have been brought about by the stoker operator, and in this respect is not dependent on steam pressure variations.

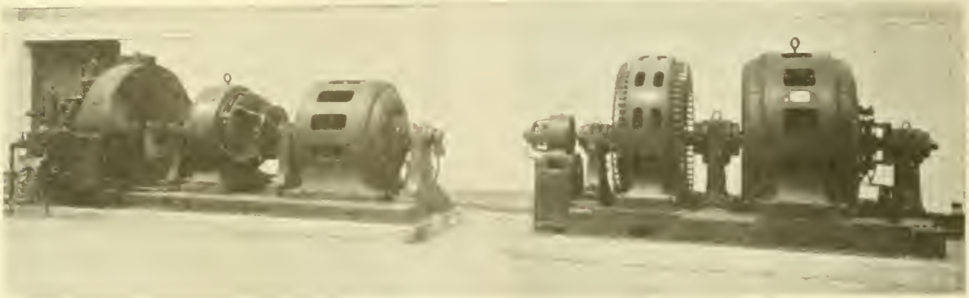


FIG. 7—DUPLEX-DRIVEN EXCITERS AND HEAT BALANCE MOTOR-GENERATOR SET

MAIN UNITS

The ultimate station will accommodate six main units. The present building will accommodate two units, and at the present writing one unit is operating and the installation of the second is progressing. These are of the cross-compound type, capable of delivering 60 000 kw continuously, and overloads up to 70 000 kw for a shorter length of time, when supplied with steam at 265 lbs. gage pressure and 175 degrees F. superheat.

The unit is divided into three elements, one high-pressure single-flow reaction turbine operating at 1800 r.p.m., and two low-pressure semi-double flow turbines, one on each side of the high-pressure element operating at 1200 r.p.m. Normally the total steam consumed by the entire unit passes through the high-pressure element, and is delivered by means of overhead pipes to

each of the low-pressure elements. The unit is designed so that at full-load each element carries 20 000 kw, and the inlet pressure to the low-pressure elements is about 55 lbs. gage. The steam supply to the entire unit is normally controlled by the governor on the high-pressure element, but each of the low pressure machines is equipped with a governor admitting live steam directly, when desired to operate them independently, thus to some extent giving the flexibility of three separate units.

The arrangement of the governors on the high-pressure and low-pressure elements is such that uninterrupted operation of each element is possible in case one or both the other elements should be shut down by the tripping of the automatic stop from any cause

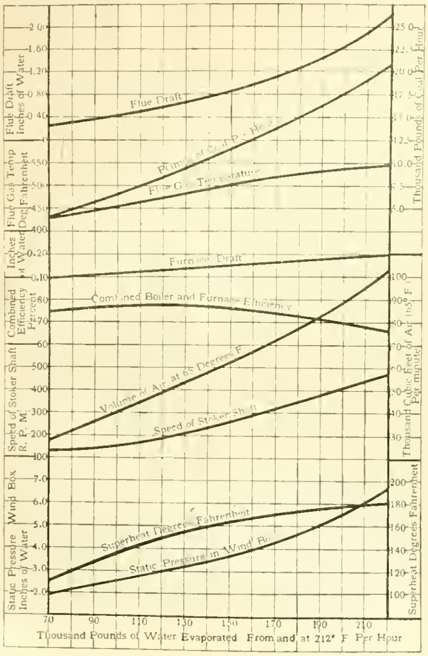


FIG. 8—CALCULATED PERFORMANCE CURVES OF 2088 HP BOILERS AND 17 RETORT, 21 TUYERE UNDER-FEED STOKERS

not effecting the other elements. For example, if one of the low-pressure elements be shut down due to overspeed or other cause, the high-pressure element will exhaust into the remaining low-pressure element, and the excess of steam will be discharged to the atmosphere through a 25 inch relief valve set to open at about 60 pounds. In this case, the high-pressure governor can be adjusted to supply only as much steam as the remaining low-pressure element can use. In case both low-pressure elements are shut down the high-pressure element can continue in operation exhausting to atmosphere. Or if the high-pressure element alone is shut down, either or both the low-pressure elements can continue to operate, taking high-pressure steam directly. Any departure from normal operation is, of course, possible only at a sacrifice in efficiency. The performance of this unit when running normally is shown in Fig. 10.

TURBINE INSTRUMENT BOARD

Each unit has its own gage board on which are mounted all electrical and mechanical instruments needed for operation. This includes two recording flow meters, two recording and integrating venturi meters measuring the discharge from the condensate pumps, two mercury manometers and various pressure and temperature indicating and recording instruments.

Indicating watt-meters and synchroscopes are also mounted on this board, the latter enabling the turbine attendant to adjust the machine speed by hand previous to synchronizing, in case the governor control motor cannot be operated by the switchboard attendant.

TURBINE OILING SYSTEM

The high-pressure oil for the governor relay and the circulation of oil to the bearings, etc., is supplied by a high and low-pressure oil pump on each of the three elements, driven from the governor shaft. In addition there are two steam driven auxiliary pumps, the operation of which is controlled by floats so that in case the main oil pumps do not provide sufficient pressure these auxiliaries are automatically cut into service. The oil coolers, three in number, are of the vertical water tube type and of such size that one cooler will provide sufficient cooling surface in case of emergency. The valves are arranged so that any cooler can be cut out of service during operation, but no matter in what position the valves are placed, it is impossible to cut out all coolers at the same time.

Purification of oil is effected by duplicate motor driven centrifugal oil separators, the oil for this purpose being withdrawn from the bottom of the reservoir tank forming the suction to the pumps. By proper arrangement of valves this purification can be made a continuous process, a part of the oil being filtered at all times.

Another feature of the oiling system is the emergency supply tank, located considerably above the turbine room floor and normally filled with clean oil from the oil separators. In case of necessity, when all other means fail, a quick opening gate valve releases this supply for lubrication of the bearings. The entire oiling system may be drained into two storage tanks, located in the basement.

STATION WATER SYSTEM

Various water and steam pipes of a general nature constitute a unified system, as shown in Fig. 11. Four different kinds of water are provided, namely, deepwell water, raw river water, condensate from the main unit, and distillate from the evaporators, and these may be interconnected in several different ways in order to insure continuous operation of the plant. The normal flow of water is as follows:—

Starting at the deepwell (as indicated in the lower right-hand corner), water is pumped to a 25 000 gallon rectangular steel storage tank on the roof from which water is taken for supplying the evaporators as well as cooling in various parts of the plant. From the evaporators the water goes either direct to the boiler feed tank or to a large 200 000 gallon concrete storage tank in the basement of the building. From this it is pumped to a condensate head tank, located directly above the boiler feed tank. These are large rectangular steel tanks, the head tank being of 25 000 gallon capacity and the feed tank 20 000 gallon capacity. From the head tank, water flows into the barometric condenser, located immediately under it, where steam from the house turbine exhaust is condensed, and the mixture or tail water descends directly into the feed tank. This tail pipe opens into a compartment in the tank from which the water flows over a V-notch in its travel to the feed pumps, which measures the amount of water passing, and any excess which might overflow passes over another set of V-notches in the same tank on its way back to the main storage tank in the basement. The supply to the head tank above is float operated, and an emergency pipe extends from the head tank to the boiler feed tank, by-passing the condenser, in which another float operated valve is located and operated by the water level in the lower tank. Any excessive demand for water that may come on the station will, therefore, effect the feed tank first, the head tank second and the storage tank third.

River water is taken from the main intake and pumped to a 21 000 gallon raw water tank on the roof. The discharge from this tank connects into the deepwell water line, so that in case of necessity this can be used in the evaporators and for all cooling purposes. This water is used mainly for wetting ashes in the ash pit about 18 in. above the clinker grinders.

In addition to the tank, large circular blow-off tanks are provided in the basement for any water which may be blown out or drained out of the boilers, and this is also pumped back into the main boiler feed storage tank by a small pump. The amount of blowoff is very small, but as the boilers themselves hold a large amount of water it is economical to reclaim this instead of losing it when it is necessary to take a boiler out of service. All other drain water, such as high and low-pressure condensation is carefully collected and piped back to the proper tank, depending on its temperature.

A small vacuum pump is provided in connection with the barometric condenser to remove as much of the air as possible to prevent its passage down into the boiler feed tank. Vacuum can be obtained from this pump only, when conditions will permit the feed water temperature to be comparatively low. A blanket of cork floats rests upon the entire surface inside the feed

FIG. 9—GENERAL VIEW OF MAIN GENERATING ROOM
The exciters and heat balance set are at the left. The house turbine is located in the alcove at the right.

storage tank for the purpose of preventing the absorption of air.

STATION HEAT BALANCE

There are only three sources of exhaust steam, namely, house turbines, boiler feed pumps and force draft fans, all other auxiliaries being electrically driven. The exhaust from the house turbine is directly connected into the barometric condenser, and the fans and pumps discharge into a common header from which the steam goes either to the evaporator or barometric condenser, depending on their respective demands. The pressure in this header however is maintained constant by a specially constructed valve which allows the excess steam from the evaporators to flow into the line to the condenser, which is always maintained at a somewhat lower pressure. In case the feed water temperature is up to normal and there is enough auxiliary load to cause an excess of exhaust steam from the house turbine, this load is shifted by the switchboard operator to the heat balance motor generator set until the required equilibrium is obtained, thereby maintaining the heat balance

FIG. 10—GUARANTEED WATER RATES FOR MAIN GENERATOR UNIT

At 265 lbs. per sq. in. gage pressure; 175 degrees F superheat; 85 percent power-factor.

of the station. As a guide to the switchboard operator in this respect a long distance feed water temperature recorder is located in the operator's room. The level of water in the various tanks is indicated electrically on a board on the main turbine room floor, by which the engineer in charge can tell the condition of the water system at a glance.

From the station wiring diagram, Fig. 12, it may be seen that the house generator feeds into a bus that normally operates at a somewhat lower frequency than the main 60 cycle bus. These are at the same voltage, however, and the motor-generator set known as the heat balance set, is connected between them. The motor is connected to the 60 cycle or transformer bus and the generator to the 57 cycle or house generator bus. The house turbine and heat balance set are controlled from the main operating gallery the same as the main unit. If the house turbine is in service and carries the entire station auxiliary load, the heat balance set will be floating on the line. If under this condition the amount of exhaust steam from the house turbine should be such as to give a feed water temperature higher than is desired, some of the auxiliary load would be shifted by the switchboard operator to this heat balance set. This would cause a decrease in the speed of the induction motor of the heat balance set, and a slight lowering of its generator frequency, and at full load on this set its frequency will drop to about 57 cycles as a minimum. Eventually, each main 60 000 kw unit will have a little power system serving it similar to this, but these small systems will be interconnected so that either the house generator or heat balance set may be used as spares for the other main units. After the second main unit is installed, the flexibility obtained in this manner will be a decided advantage in the operation of the station. It is entirely possible, of course, to transfer the entire load to the main transformer bus by means of the bus tie switch shown near the center of the diagram, but this will eliminate the safety features of the house service system.

EVAPORATOR

The vapor from the evaporator is condensed in a small condenser, the cooling water for which is the condensate from the main turbine. Thus, the heat given off in this condenser finds its way back to the boilers with no loss in the evaporating process except radiation and a small amount of leakage of hot concentrated water. Fig. 13 shows schematically the action of the evaporator. This unit, capable of distilling 15 tons of raw water per hour, consists of three cylindrical shells, two of which known as "effects" are lettered for convenience *A* and *B*, the third being the surface condenser. On the left hand sketch, the exhaust steam from the forced draft fan turbines and the boiler feed pump turbines enter effect *B*. The raw water enters effect *A* according to the diagram, but in our practice it is admitted into the hot effect. The circulating pump, located immediately below each effect, raises this raw water to the top of the effect and discharges it in a spray over the tubes. The steam on the inside of the tubes causes the raw water to vaporize and these vapors pass off into the cool effect *A*. The operation of the second effect is the same as that of the first, except that the vapor from the first evaporates more raw water in the second effect. The resulting vapors pass on to the condenser. The steam which enters the tubes in both effects is condensed, and the resulting water flows back out of the tubes into traps in the steam end of each effect. This water from both effects flows together into a flush chamber where it bursts into steam which then enters the condenser.

The right hand sketch shows the operation of this unit after "reversing". In this sketch the exhaust steam enters *A*, *B* now being the cold effect. Reversing the operation of the evaporator causes a change in temperature of each effect which, due to the resulting expansion, tends to crack off any scale that might have formed. The scale is then precipitated and is carried away through a residual water connection.

CONDENSERS

Each main unit has 100 000 sq. ft. of condensing surface contained in four shells, one for each of the low-pressure exhausts. Each shell is further subdivided in two sections so that one-eighth of the total surface may be isolated for cleaning. This has proven to be of advantage where a large quantity of leaves bank against the revolving screens and some find their way into the condensers.

The tubes in these condensers are somewhat special in that they are expanded into the tube sheet on one end and pass through the other end through the ordinary packing box. The tubes are supported at the center only and raised slightly at this point. There is considerable sand in the circulating water which, up to the present time, has had a tendency to polish the tubes. These pumps are rated at 44 000 gallons per minute and operate at 480 r.p.m. The pump suction and discharge valves, 72 in. and 63 in. respectively, together with inlet valves to each of the condenser sections, are hydraulically operated by water from the boiler feed lines. The waste water from these operating cylinders, together with the various overflows and drains from gland water seals, etc., is collected and delivered back to the system by means of a small float-operated condensate reclaiming pump.

CONDENSATE PUMPS

There are installed four motor-driven two-stage condensate pumps. With maximum load on the unit, only two of these pumps are required. The others serve as spares. An emergency connection has been provided so that, in cases of extreme contamination, the

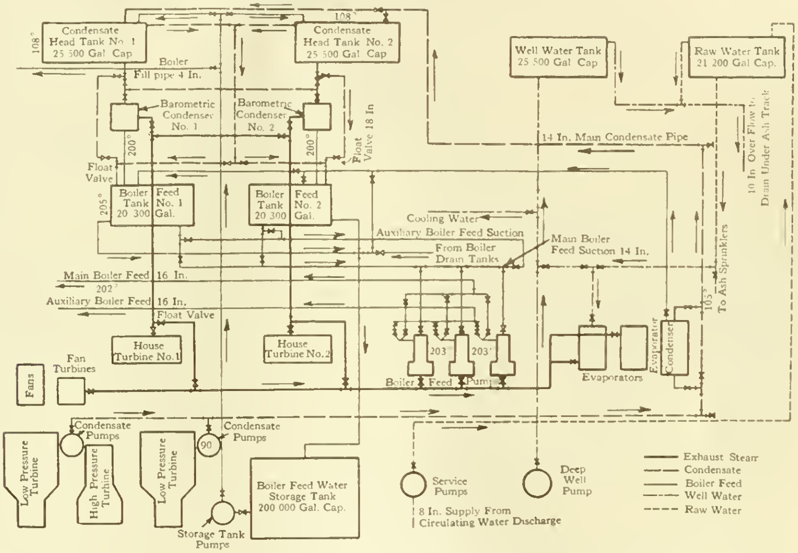


FIG. 11—FEED WATER FLOW DIAGRAM

The temperatures on the diagram correspond approximately to the temperatures in the various parts of the system during normal operation.

water from the condensate pumps may be discharged to the river.

Valves on the discharge from each condenser section are motor operated. Any degree of regulation of the quantity of cooling water can thus be obtained. As a further means of regulating condenser temperatures a gate may be opened, permitting the discharge circulating water to be recirculated through the condensers.

The guarantee performance of these units is shown in Fig. 15 and their preliminary operation seems to indicate that their performance under full load will approximate these values.

CIRCULATING PUMPS

For each unit, three centrifugal motor-driven pumps are provided discharging into a 60 inch common header so that any pump or combination of pumps may be used to supply circulating water to the condensers.

AIR PUMPS

Three Leblanc air pumps are installed for air removal purposes. These pumps receive their hurling water from and discharge into two concrete tanks below the basement floor. The supply of cold water is obtained through a hand-regulated valve fitted with twin strainers and connected to the discharge header of the circulating pumps. The overflow from these tanks flows into another concrete tank from which it is removed by means of two float-controlled, electrically-driven removal pumps. It is planned to install a rotative dry vacuum pump in connection with an :: bell for the purpose of measuring the air leakage.

FORCED DRAFT FANS

The fans are of the horizontal double inlet type, delivering 250 000 cu. ft. per minute. They are driven at variable speed by steam turbines through reduction gears, and are controlled from the station steam pressure by means of regulators. Each fan unit is capable of supplying air for 40 000 kw of load continuously, and three fans are provided for 120 000 kw of turbine capacity.

There is a definite path of air through the station as follows:—Openings are provided in the building wall on the river side and covered with metal curtains in such manner that air to the air washers can be obtained from the outside, inside or both at the same time. The air path is a closed circuit from the washers to the generators, but the passages are large and contain the main generator leads. The path through the generator is up through the end bells along the air-gap through the stator and down into another duct leading to the forced draft fan room. This fan room is inclosed on three sides only, the open side connecting into the ash cellar. From the forced draft fan the air path is completed to the top of the stack.

ELECTRICAL EQUIPMENT

The electrical end of Colfax power station has been so designed that each 60 000 kw generating unit will be entirely separate and isolated from the other units. Each unit comprises three main generators; a station service generator; a bank of step-up transformers; a bank of station service transformers; one exciter; and one heat balance motor-generator set; with the necessary bus structures and control boards. The only interconnection to be made between units will be on the 66 000 volt busses, which supply the out-going feeders. As the reactance of the main transformers is included in the circuit between the generators and the busses on which the generators are paralleled, there is no need for bus-bar reactors. This arrangement greatly simplifies the wiring, reduces the number of circuit breakers and minimizes the possibility of trouble. It is made possible by the location of the station at a point where there is little local load, so that normally the entire station output is transmitted at 66 000 volts. All 12 000 volt connections from the main generators to the main step-up transformers are of bus construction or its equivalent, thereby reducing the chances of a short-circuit to a minimum. All busses are in duplicate. The main 12 000 volt busses are mounted in rooms separated by a fire-proof structure, as shown in Fig. 19. The station service busses are sufficiently separated to prevent trouble on one bus from spreading to the adjacent busses.

GENERATORS

The three generators of the unit are each rated at 20 000 kw at 85 percent power-factor, 12 000 volts. They are normally operated as a single unit, being brought up to operating frequency and voltage in synchronism, with the fields excited, steam being supplied to the high-pressure cylinder only. They are normally synchronized with the 66 000 volt system by means of the circuit breaker between the 12 000 volt bus and the main transformer bank.

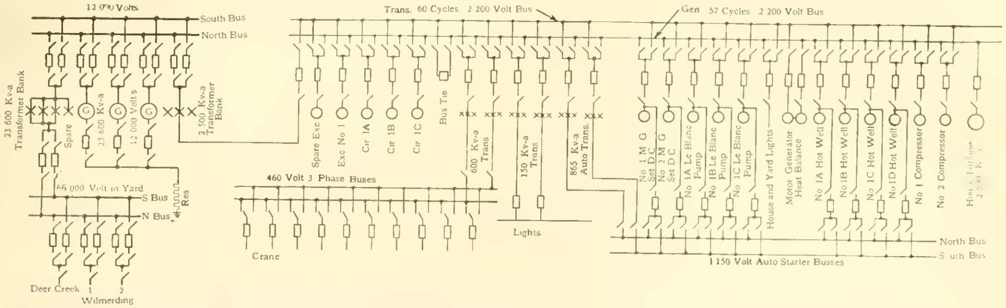


FIG. 12—SCHEMATIC DIAGRAM OF MAIN AND AUXILIARY BUSSES

On the revolving fields of each generator are mounted fan blades which draw air from the air washer, forcing it through the generator laminations and windings. After passing through the generators, the heated air is used for forced draft purposes in the boiler room, thereby resulting in more economical operation.

Each generator is protected with differential relays so that in case of internal grounds or short-circuits in the windings or leads to the 12 000 volt bus, it will immediately be disconnected from service, the field circuit breaker and the over-speed device of the steam turbine being tripped, so as to minimize the damage that might result from such occurrence. In addition to this protection, steam connections are made to perforated pipes beneath the generator windings, so that in case of fire, steam can be turned into the generator casing to smother the flames. At the same time dampers in the air ducts can be closed by remote control from the switchboard, effectively smothering the flames.

Each generator element has a ground connection from the neutral of the star through a resistance, rated at seven ohms and 1000 amperes for two minutes, and a circuit breaker with disconnecting switches. A signal

lamp and alarm bell in the control room are connected to a current transformer in each generator ground circuit beyond the star connection, to notify the station operator when a ground has occurred. Only one of the generators is normally grounded at a time, in order to avoid circulating currents, and the circuit breakers in the ground circuit are so interconnected that the closing of any one will automatically trip out any other that is closed.

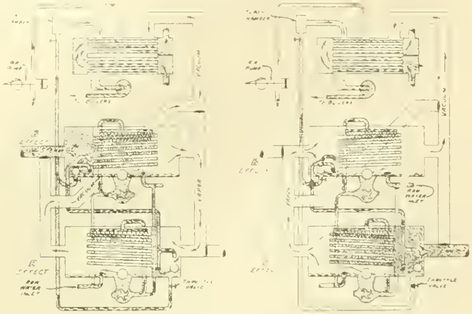


FIG. 13—FLOW DIAGRAM OF STEAM AND WATER THROUGH THE EVAPORATORS

The leads from each generator element are provided with eight 1600-5 ampere current transformers of the through type, which furnish current to three alternating-current ammeters (0-1600); one polyphase wattmeter (0-30 000 kw); one direct-current field voltmeter (0-300) which also has a scale in red which indicates amperes when the fields are at normal operating temperature; one polyphase wattmeter type differential relay; one polyphase watthour meter. For taking internal temperatures of the generators, six resistance coils and six thermocouples are mounted in the slots of each armature and connections are made to a potentiometer in the control gallery.

The leads from the generators to the 12 000 volt bus room consist of two 1 000 000 circ. mil cables for each generator phase. These cables are insulated with varnished cambric with a braided covering for 15 000 volts and, as an additional factor of safety, are mounted on 25 000 volt duplex porcelain insulators. For convenience they are carried under the floor in the generator air ducts.

The main switchboard in the control room is shown in Fig. 16. The control desk has seven sections, which are, from front to back:—exciter and Tirrill regulator; house turbine and transfer switches; heat balance; station transformers; main transformers; main generators; face plate regulators. The instrument panels are mounted directly behind the corresponding panels on the control desk. The high-tension feeder board is at the rear of the control desk. The battery board from which all direct-current control circuits are manipulated is at the right, and in the foreground at the right is the potentiometer pedestal for the generators with a switchboard type potentiometer calibrated in degrees C. and a group of revolving dial switches for connecting the thermocouples to the potentiometer. Mounted on this same pedestal is the control for a large illuminated sign mounted in the boiler room, by means of which the switchboard operator can signal the load in kw that is being carried or that is expected. A telephone switchboard gives immediate access to all parts of the plant and a loud speaker permits the operator to talk without the use of a head set. The one shown in Fig. 16 is duplicated with a parallel equipment, so that connections between points in the plant or to the outside can be made without disturbing the switchboard operator.

A duplicate system of voltage control is installed. Principal reliance is placed upon a face plate regulator, which consists of a large high speed motor-operated rheostat mounted in the main field circuit of each generator. These rheostats are actuated through a group of control coils by a balance between the exciter voltage and the voltage of the main generator, in much the same manner as is done in a Tirrill regulator. To prevent over-shooting, they are arranged to advance by small steps, which are quickly repeated until the desired voltage is maintained. As the face plate regulator influences the fields of the generator directly, it eliminates the time lag which is inherent in regulating the field of the exciter. Also in case the contacts stick there is not produced the extreme fluctuation in voltage, which occurs with the Tirrill regulator. As an auxiliary system of voltage control, a standard Tirrill regulator is provided which operates on the exciters in the usual way. A Tirrill regulator is also provided for the house turbine and heat balance generator.

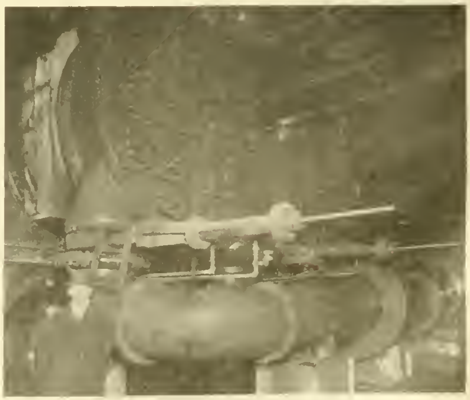


FIG. 14—PAIR OF MAIN CONDENSERS

Showing also the circulating water piping and the hydraulically-operated gate valves.

An induction regulator type signal system is installed for transmitting signals between the control room and the gage boards near the main turbine. The transmitter consists of a small induction regulator with a three-phase wound rotor connected to a standard 60 cycle source of supply, and a single-phase stator which

is connected to duplicate position indicators, one at each station. The position indicator is a standard power-factor meter whose dial is marked with the signals desired instead of the usual power-factor scale. As both position indicator needles follow closely the position of the transmitter, any desired signal can be given. The signal is answered by replying with the same signal on a similar equipment, operated from the turbine gage board. A push button signal is also used to call the attention of the operator to the signal indicator, which sounds an air whistle and lights a signal lamp in the turbine room or sounds a buzzer and lights a lamp in the control room.

EXCITATION SYSTEM

For each 60 000 kw unit there is one 350 kw shunt wound exciter. This exciter is duplex driven from an induction motor and a direct-connected turbine. Normally, the generator will be driven from the motor end, with a small amount of live steam bled into the turbine through the governor; if, in case of trouble, the speed of the set should fall below normal, the steam turbine automatically picks up the load. In addition to this exciter, there is a duplicate exciter which will be used as a spare for all units.

MAIN TRANSFORMERS

The main step-up transformers consist of three 23 600 kv-a water cooled transformers. They are connected delta on the primary side and star on the secondary. These transformers, like all the other high-voltage apparatus in the station, are designed to operate at 132 000 volts, and are the largest single-phase transformers built by the Westinghouse Company to date. Differential relays are so connected that, in case of grounds or short-circuits either in the transformers or the connections to them, they will be disconnected from service immediately. A fourth transformer of the same capacity is mounted adjacent to the others and can readily replace any of them in case of trouble. The spare transformer is connected to the piping system for water cooling and is arranged for quick connection in place of any of the others by means of removable pipe links on the high-voltage side and disconnecting switches on the low-voltage side. The transformers are mounted on rails, and doors are provided so that any of the transformer units can be run into the turbine room where the station crane is available for repairs.

The high-voltage neutral of the transformer bank is grounded through a resistance of 95 ohms. A current transformer is connected in the ground circuit, which actuates an alarm bell and a signal lamp in the control room and is also connected to a graphic meter.

HIGH-TENSION BUSSES

Comparative designs showed that in this particular station it would be cheaper to place the high-tension transformers and circuit breakers indoors rather than outdoors. Inasmuch as the standard outdoor spacings of bus-bars has been secured in this interior installation, it is also considered that the reliability of operation is improved, and any repairs can be effected more easily. The general arrangement of the indoor 132 000 volt structure is shown in Figs. 5 and 17. The disconnecting switches between the transformers and circuit breakers are of the gang operated, three pillar rotating type, manipulated from the floor by handles which are normally kept locked. The leads from the indoor 132 000 volt circuit breaker pass directly up to duplicate high-tension busses on the roof through high-tension wells as shown in Figs. 5 and 18.

CIRCUIT BREAKERS

All of the oil circuit breakers are of the remote-control solenoid-operated type. As shown in Fig. 19, the main 12 000 volt oil circuit breakers are mounted

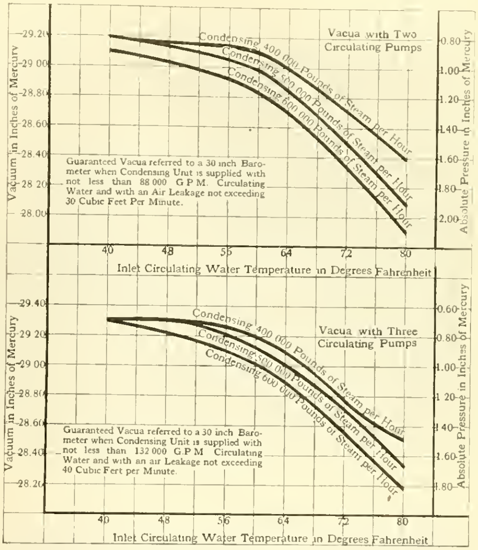


FIG. 15—GUARANTEED CONDENSER PERFORMANCE
For 100 000 sq. ft. surface condensers.

adjacent to the 12 000 volt bus chamber. The 132 000 volt oil circuit breakers between the main transformers and the 66 000 volt busses are mounted on the main floor of the electrical bay. When actuated by instantaneous relays these circuit breakers are capable of rupturing 12 400 r.m.s. amperes per phase at 66 000 volts.

The 2200 volt circuit breakers for the auxiliaries are mounted in cells, as shown in Fig. 20. All these circuit breakers are provided with red and green lights at the circuit breaker as well as on the switchboard, to indicate whether they are open or closed. In addition a small double-pole push-button switch is mounted just above the circuit breaker, which interrupts the control circuit, preventing the operation of the circuit breaker. This switch also serves to light a white lamp if the circuit breaker is in the open position, but a pallet switch on the circuit breaker prevents the lighting of the white

lamp if the circuit breaker is closed. This arrangement provides an additional source of safety to anyone desiring to work on the circuit breaker or operate the disconnecting switches.

STATION SERVICE

As the majority of the auxiliaries are electrically driven, duplicate sources of power supply have been provided, as shown in Fig. 12, viz., either from the main generators or the house generator. All motors over 100 hp are operated at 2200 volts, while the smaller ones operate at 440 volts. Being located so close to a very large source of power supply, all the 2200 volt motors have their main connections made through oil circuit breakers. The 600 hp circulating pump and 100 hp compressor motors are of the wound-secondary type and these are started by drum controllers mounted beside the motors. The secondary connections are handled by the drum directly, but the primary connections are remote control through a contact on the drum. The heat balance motor and the exciter motors, which are also of the wound-secondary type, are arranged for unit switch automatic acceleration, the exciter motors being started from push button stations near the units, while the heat balance motor is started from the main switchboard.

All other auxiliary induction motors are of the squirrel-cage type. They are started from a low-voltage bus as shown in Fig. 12, through oil circuit breakers, which are actuated by push button control alongside the motor, each push button station having three positions marked *Start, Run* and *Stop*. The circuit breakers for connecting these motors to the starting and running positions are interlocked electrically and are provided with sequence relays so that it is impossible to connect a motor to the running position without first connecting it to the starting position, and it is also impossible to connect it to both positions simultaneously.

The adjustable-speed stoker and clinker grinder motors receive their supply from 250 volt direct-current motor-generator sets, which are in duplicate.

HEAT BALANCE MOTOR-GENERATOR SET

As the exhaust from the house turbine is used for heating the feed water, it is necessary to vary the load on this unit, in order to maintain a constant temperature. This is accomplished by transferring the load from the house generator to the main generators or vice-versa. In order to provide closer adjustment than could be obtained by paralleling the house generator directly with the main generators, a motor-generator set consisting of a synchronous generator driven by an induction motor is connected between the two systems, as shown in Fig. 12. The governor of the house turbine is controlled by a motor actuated from the switchboard so as to give any desired speed between 57 and 60 cycles. When more steam is needed from the house turbine to raise the feed-water temperature, as indicated by a feed-water graphic thermometer located on the instrument board, its speed is increased so that it carries a larger percentage of the auxiliary load and the heat balance generator a smaller percentage. The load carried by the heat balance generator is obviously proportional to the difference in frequencies between the bus bars, as the heat balance motor will carry no load when the two bus-bars are operating at the same frequencies. This set is protected with relays that automatically disconnect it from service, thereby separating the two systems, in the event of shutting down the main unit, or other disturbances that would cause a large difference in frequency between the two systems.

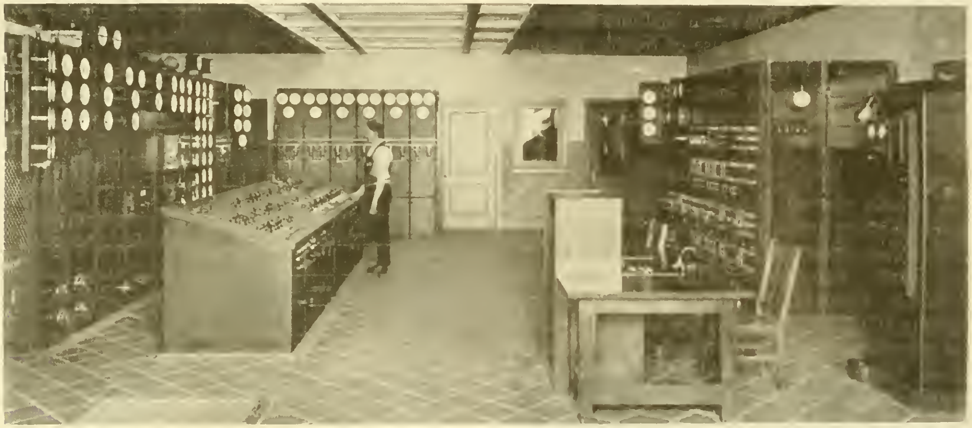


FIG. 16—MAIN SWITCHBOARD AND CONTROL ROOM

The instrument board and control desk are at the left; thehigh tension feeder board is at the rear of the room; the battery and direct-current control board is at the right; and the potentiometer pedestal is in the right foreground. The telephone switchboard gives instant communication with all parts of the plant.

The heat balance motor-generator set provides a system of controlling the heat balance of the station which is at once flexible and sensitive. This arrangement also requires that any disturbance on the main bus-bars must be serious enough to produce a decrease in frequency of approximately five percent before the house turbine is separated from the main bus bars, which is a great advantage over any system which requires that these units be disconnected with any decrease in main bus-bar frequency.

It will be seen from Fig. 12 that, if the disconnecting switches between the 60 cycle and 57 cycle, 2200 volt busses and the auxiliary circuit breakers were closed simultaneously, the house generator would be connected with the main generators out of synchronism. To prevent this, these busses and disconnecting switches are mounted back to back on opposite sides of the same wall, and a rod running through this wall, in guides serves as a mechanical interlock, to prevent these disconnecting switches being closed simultaneously. A bus-tie circuit breaker is provided, however, to tie these two busses together if the house turbine is shut down or if, for any reason, it is desired to synchronize it with the main unit.

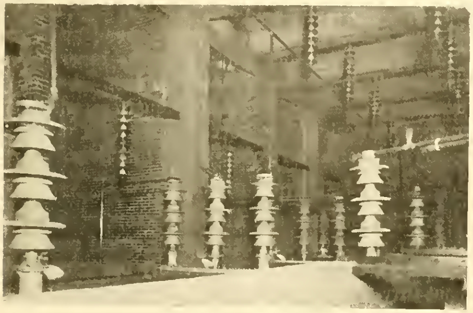


FIG. 17—132 000 VOLT BUS STRUCTURE IN THE TRANSFORMER ROOM

CONTROL SYSTEMS

All the oil circuit breakers and relays are operated by direct current, supplied by two motor-driven compound-wound generators and two batteries, which are connected to a double bus structure located in the control gallery. With the switching arrangement provided, it is possible to charge and discharge the batteries without varying the control voltage; further, isolation of grounded control circuits from the regular control system is also permitted. Trip coil supervision is obtained by connecting a red pilot lamp in series with the trip coil. A resistance is connected in the pilot lamp circuit to prevent a large flow of current in case of a pilot lamp or its fixtures short-circuiting. All control cables throughout the station are properly tagged to assist the maintenance men in locating trouble.

ARCHITECTURAL FEATURES

The building proper is of red brick exterior, and light brick interior, with white face brick wainscoting, slate baseboard and red tile floor. The steel stacks are supported from the building structure and from special steel reinforcing built from the ground. The windows are of translucent glass in steel frames and all louvre windows are motor operated. The interior finish varies from white to black through a series of grey colors. Some small offices are of the lighter colors, while the main bulk of the mechanical equipment is of medium grey. No color distinctions are made in piping, these being distinguished by stenciling.

FIG. 18—132 000 VOLT DOUBLE BUS STRUCTURE ON THE ROOF OF THE POWER STATION

The high tension wells from the oil circuit breakers appear at the left.

The station is built close to the Allegheny River, with the Conemaugh Division lines of the Pennsylvania Railroad immediately on the other side. It is in open country surrounded by desirable residential boroughs. The substructure of the building is a slab of concrete 9 ft. thick, thoroughly water-proofed, and with the necessary tunnels, tanks and sumps provided in the concrete for the main unit auxiliaries. Standard gage tracks for the removal of ash and machinery are on the main floor elevation.

Space has been provided on the ground floor elevation underneath the boiler room for a machine shop and storage of heavy parts. This space is inclosed by solid tile partitions to keep out moisture from the ash cellars on each side and is supplied with forced ventilation from the main air ducts overhead.

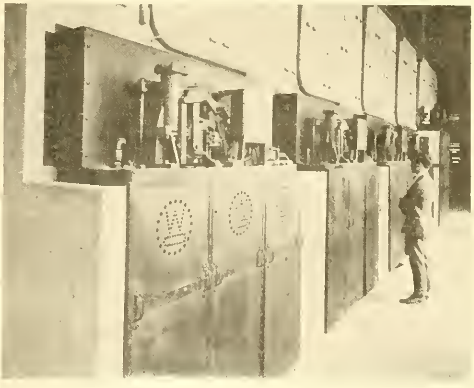


FIG. 19—MAIN 12 000 VOLT CIRCUIT BREAKERS AND BUS STRUCTURE

Absolute fireproof construction is maintained throughout the building, windows, doors, office furniture, lockers,and cupboards being of fireproof construction. A sea wall on the river front is provided for, and a spacious yard on either side is at present being filled in and leveled off to improve the general appearance.

There is an architectural distinction to the plant both form external and internal appearance. The symmetrical layout of main units as observed from the upper balconies, the height of the turbine room as observed from the main floor, the ornamental lighting and main crane constitute a view that is imposing. From the simple standpoint of magnificence it has an appeal to those who delight in seeing any structure so well built as to defy the ravages of time and decay.

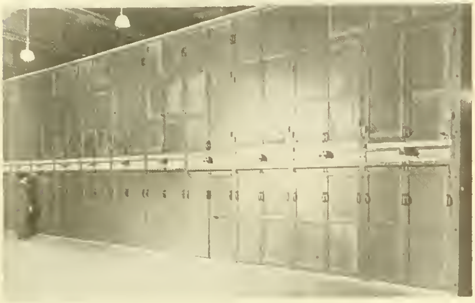


FIG. 20—2200 VOLT CIRCUIT BREAKER AND BUS COMPARTMENTS FOR STATION AUXILIARIES

Locker Rooms—On account of the magnitude of the plant, locker rooms, shower baths and toilet rooms are conveniently located on several different elevations for the use of the nearest group of operators. It is believed that this offers considerable advantage over any centralization of these features.

Station Offices—A large space is provided on the upper floor over the electrical bay for the general station offices, reached by an independent elevator. On this floor is also the station telephone exchange, which is attended by a special operator during the day and by the switchboard operator on a duplicate control board at night. A repair room for small electrical repairs and instrument work is provided on this floor, near the main control room, also the battery room, conference room, ladies rest room, toilet and locker rooms.

COAL SUPPLY

A special track for coal supply enters overhead at the boiler room floor level. A gantry crane is to be made use of in the future for stocking coal, but for the present a stock of coal in the yard is handled by a locomotive boom crane. This coal is piled to a maximum height of about 15 feet to prevent overheating and ignition. The plant is located about a mile from the mine shaft which will supply coal throughout its contemplated existence. The extent of this field owned by the Company is shown on the map in Mr. Stone's article.

Coal Tower Space—The space occupied by the coal tower is utilized to house the cafeteria, sleeping quarters, store-room and time-keeping office on different elevations. The noise from the operation of the coal elevator is heard during a part of the day only, and any coal dust which might be expected around machinery of this kind is carefully avoided by the generous use of solid walls to completely isolate all dust. Automatic elevators give easy access to these quarters, which are arranged vertically, one above another, with the time-keeping and watchman's office on the first floor.

STATION PERSONNEL

A chief engineer and three assistants in charge of the boiler room, turbine room and electrical equipment respectively, constitute the supervisory operating force. About fifty operating men and thirty maintenance men will complete the regular force when the first unit is running at full capacity and all equipment has been taken over.

In order to carry on tests, special investigations, time studies and general power station betterment, about six men, known as test engineers, work under the special direction of the superintendent of power stations and in co-operation with the station chief engineer.

TABLE I—GENERATING CAPACITY OF DUQUESNE LIGHT COMPANY POWER STATIONS

Power Station	No. of Electric Units	Rated Capacity Each (Kw.)	Type	A. C.	D. C.	Total Rated Generating Capacity (Kw.)	Number of Boiler Units	Rated Capacity Each (Hp.)	Total Rated Boiler Capacity (Hp.)
Brunot Island	1	3 000	H. P. Turbine				19	500	
	5	15 300	H. P. Turbine	119 500		119 500	10	600	
	1	40 000	H. P. Turbine				7	822	
							20	822	37 694
Colfax	1	60 000	H. P. Turbine	60 000		60 000	7	2088	14 616
Rankin	2	1 500	L. P. Turbine				18	300	
	1	3 000	L. P. Turbine				2	686	6 772
	5	750	P. I. W. Engines	9 750					
	4	500	P. I. W. Engines		2 000	11 750			
Thirteenth St.	1	8 000	H. P. Turbine	8 000			2	350	
	1	1 500	R. & S. Engines		1 500	9 500	6	350	
							2	250	
							12	250	6 300
Twentieth St.	8	800	P. I. W. Engines		6 400	6 400	16	375	
							2	400	6 200
Glenwood	1	2 000	H. P. Turbine				2	375	
	2	900	R. & S. Engines	3 800			4	400	
	4	500	Green Engines		2 000	5 800	2	325	
							3	300	3 900
Total	37			201 050	11 900	212 950	134		75 482

The Transmission Ring of the Duquesne Light Company

E. C. STONE
Asst. to General Manager,
Duquesne Light Co.

WITH the starting up of the Colfax power plant and the closing of a ring of 66 000 volt lines around the Pittsburgh District, a super-power system has been established for supplying the City of Pittsburgh and the greater part of Allegheny and Beaver Counties with electric energy, a system which is adequate for all present needs and capable of development to almost unlimited capacity.

The problem of transmitting power in sufficient quantity into the metropolitan district of Pittsburgh, even from the Brunot's Island Plant, has been recognized as a most serious one for several years. The business district is packed into a very small area near the meeting of the rivers, and the manufacturing districts have been concentrated along the river banks. Between the power plant and these districts is a closely built up territory with narrow, inadequate streets. To transmit power in any quantity through this territory by overhead lines could not be considered because of congested conditions, and to transmit it in sufficiently large quantities underground was almost as impracticable because of the enormous quantity of heat that would be developed at the relatively low maximum voltage at which underground cables can be operated.

The system then in operation, consisting of underground lines along all available streets, had already reached its limit, so that a radically different scheme had to be developed in order that it might be possible to deliver all of the power required into the congested metropolitan business and manufacturing districts. After careful study, a high voltage transmission ring encircling the district was decided upon. This looked particularly attractive because the location of the Colfax plant was such that, with the Brunot's Island Plant, the two main sources of power supply would feed into such a ring from points almost diametrically opposite.

The working out of this transmission ring has solved the problem effectively. By it, a practically unlimited amount of power can be transmitted from the two main power plants, over transmission lines unrestricted by their surroundings as to voltage or physical construction, to a number of points readily accessible to different parts of the main industrial district. From these points, at which stepdown sub-stations are located, enough routes are available for transmission at 22 000 volts of all power that is now required or is likely to be needed in the future for the metropolitan district and surrounding territory. These substations are located so near the power using districts that transmission is accomplished at 22 000 volts without excessive cost.

Furthermore, the transmission of the total power supply from the substations into the city over so many routes, which are entirely independent of each other and physically a considerable distance apart, makes for reliability of service, since any trouble condition in a given location such as lightning, fire or external interference can interrupt only a relatively small part of the total.

The high power transmission ring encircling the metropolitan district also makes an adequate and reliable supply of power available to all of those undeveloped districts immediately around the congested area. Already some of the surrounding districts have developed very rapidly through the availability of Duquesne Light Company power. One of the most notable of these is the Bridgeville area, which now uses some 25 000 kilowatts and has had its entire power development since the lines of the Duquesne Light Company made central station power available in that area.

In short, such a high voltage transmission ring is the only scheme by which it is physically possible to meet the growing demands for power in the congested areas of metropolitan Pittsburgh. It was realized, however, that the success of the scheme would be dependent on its reliability, that is, on its ability to deliver power continuously as well as in sufficient quantity. Hence, the greatest stress has been laid on this requirement.

The layout of the transmission system now in service and under construction, which will take care of 120 000 kw from Brunot's Island and 120 000 kw from Colfax, is shown in Fig. 1. On this map is included the location of the main and peak load power stations, principal substations, 66 000 volt transmission ring and the principal 22 000 volt and 11 000 volt transmission lines.

The 66 000 volt transmission ring consists of a system of lines encircling the city and fed from opposite ends by the two main power plants, Brunot's Island and Colfax, with a spur extending down the Ohio River to feed the Ohio and Beaver River power districts.

Eight stepdown substations have been installed at eight points in the ring, as shown, for the purpose of stepping the voltage down to 22 000, for which voltage the spurs from the substations into the power district are built. Hence, including the lines from the ring substations and the two underground lines already in ser-

vice from Brunot's Island, the power supply is carried into the district over ten distinct routes.

In order that the service rendered by the transmission ring might prove adequate to meet the exacting power demands of the Pittsburgh industrial district, the problems to be encountered in its operation were carefully studied in advance and the electrical and mechanical details of the system were worked out with a view to obtaining the very best possible operating conditions. A voltage of 66 000 volts was adopted for this system because it was sufficiently high to give good transmission economy for the distances involved and not high enough to introduce risks from insulator trouble which might arise from the large amount of carbon in the air in the territory covered. In accordance with the experience on other systems, it has been found that the insulation of these lines is sufficiently strong to protect them against most lightning disturbances and that there is less trouble from lightning on these lines than on the lower voltage lines.

The result of these preliminary studies was a decision that the transmission system, including lines and substations, must meet the following requirements:

a—All lines and equipment must be designed with the

FIG. 1—TERRITORY SERVED BY DUQUESNE LIGHT COMPANY

TRANSMISSION SUB-STATIONS

Station	Installed Capacity Kv-a
Ambridge	18 750
Cheswick	12 500
Deer Creek	11 250
Dravosburg	12 500
Junction Park	15 000
North	25 000
Wilmerding	20 000
Woodville	25 000

DISTRIBUTION SUB-STATIONS

No.	Station	Installed Capacity Kv-a
1	Allegheny	2790
2	Allison Park	600
3	Ambridge	1430
4	Beaver Falls	3125
5	Bellevue	930
6	Bloomfield	1565
7	Carnegie	1875
8	Christy Park	3375
9	College Hill	2450
10	Crafton	930
11	East End	11 250
12	Economy	3500
13	Esplen	1875
14	Exposition	620
15	Fallston	1875
16	Forty-eighth Street	3750
17	Frick	8065
18	Hazelwood	930
19	Homestead	1000
20	Homewood	1875
21	Imperial	600
22	Kennywood	560
23	Manchester	3750
24	Midland	375
25	Milltown	1500
26	Monaca	1500
27	McKeesport	4680
28	McKees Rocks	1000
29	New Brighton	930
30	North Side	1395
31	Oakland	3750
32	Ontario Street	2805
33	Phipps	3665
34	Point	375
35	Rankin	4680
36	Rochester	2645
37	Sarah Street	3750
38	Sewickley	1500
39	Sixty-second Street	2790
40	Soho	2000
41	South Hills	930
42	South Heights	12
43	Thirteenth Street	15 000
44	Thirtieth Street	7500
45	Tunnel	2895
46	Verona	1395
47	Washington Junction	375
48	West End	375
49	William Penn	3230
50	Wilkinsburg	3000
51	Wilmerding	2000
52	Wilson	1550
53	Woodlawn	2100
54	Woodville	930

greatest factor of safety consistent with reasonable economy, with a view to giving the most reliable operation possible.

b—Sufficient spare capacity and duplicate equipment must be installed throughout to carry the loads satisfactorily without curtailment under conditions of breakdown reasonably to be expected.

FIG. 2—TRANSMISSION LINE CROSSING MONONGAHELA RIVER AT DUQUESNE

The conductors are stranded aluminum cables with 3/8 inch stranded steel core, having a conductivity equivalent to 4/0 copper. The tower in the foreground is 200 ft high and the one on the hill-top is 100 ft. high.

c—Disturbances due to breakdowns and other causes must be reduced to a minimum.

d—The power supply to the various sub-stations must not be interrupted by ordinary failures on the transmission system. In every case defective lines or equipment must be promptly and completely isolated from the rest of the system.

e—The two principal power plants must be solidly tied together by the transmission ring. Ample synchronizing power must be provided and the two plants must not be broken apart by short-circuits or other disturbances in the ring or on other parts of the system.

f—Satisfactory voltage conditions must be provided at the sub-station busses, and provision must be made for the proper distribution of wattless current between the power plants.

Requirement *a* was met by providing liberal factors of safety, mechanically and electrically, on all equipment. To take care of the requirement *b*, ample line capacity is provided, so that all loads can be carried under reasonable breakdown or maintenance conditions. Substations are equipped with duplicate busses and duplicate transformers. The interconnecting 22 000 volt lines between the various substations are such that any one substation could be taken out of service and all of its load carried from the remaining substations. Finally, if necessary, all of the power required for the territory could be handled over eight of the ten transmission routes feeding in from the 66 000 volt substations and from Brunot's Island.

The 66 000 volt transmission circuits are carried on steel towers. Each tower carries two three-phase circuits and two ground wires. The towers are of substantial construction and are considerably heavier than average practice would indicate for this class of work. On the average there are six towers per mile.

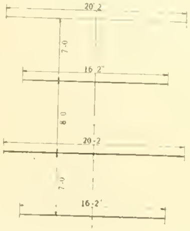


FIG. 3—ARRANGEMENT OF WIRES ON TOWER

For the greater part of the system, each circuit consists of three 4/0 bare stranded copper cables. One section of the line, however, from the Monongahela River crossing west to Woodville, a distance of about 18 miles, is constructed of aluminum cable with steel core. This conductor has a conductivity equivalent to 4/0 copper and its core is a seven-strand steel cable,

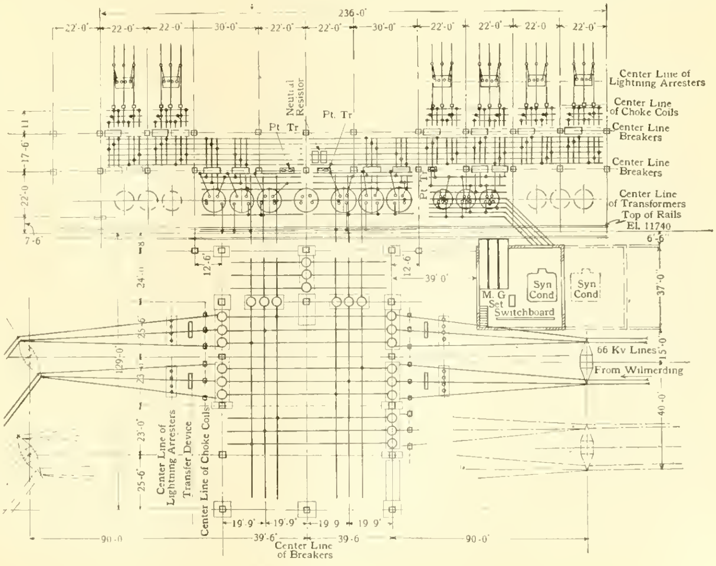


FIG. 4—DIAGRAMMATIC PLAN OF DRAVOSBURG SUBSTATION

5/16 in. in diameter. The aluminum cable was installed in conformity to the standard specifications of the Aluminum Co. of America, by whom it was furnished. This section was put in as an experiment and its performance will be carefully compared with the performance of the adjacent copper circuits.

The spans over the Allegheny and Monongahela Rivers, the latter being 2360 ft. between towers and the longest span on the system, are both of steel core aluminum cable as described above. Throughout the system, the ground wires are of 3/8 in. stranded steel cable. Suspension insulators are used, there being five units in the suspension strings and six in the strain strings. The porcelain used in the insulators when under strain is in compression rather than in tension. Each insulator unit will require approximately 95 000 volts for flashover and 140 000 volts for puncture. A high factor of safety above operating voltages is thus assured.

The right-of-way selected for the 66 000 volt line was made as near to the city power districts as possible, without placing any limitations on adequate construction. Towers are located on private rights-of-way and, because of this and their rugged construction, they will be practically free from external interference, which is the cause of so many failures on ordinary pole lines.

The substations, like the lines, are of the simplest and most rugged construction. It will be seen from Fig. 5 that all incoming lines are sectionalized where they enter the station, and that two transformer banks are installed, each transformer bank being controlled by a separate switch. A tie switch is also provided by which both transmission circuits can be operated in parallel.

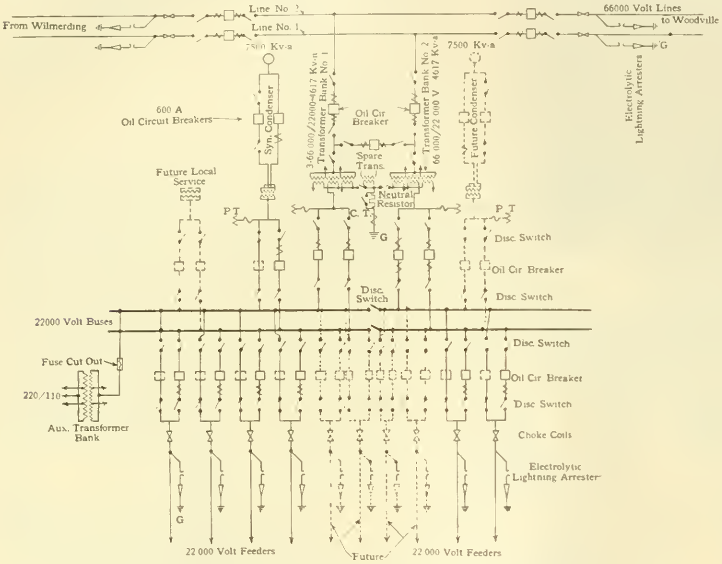


FIG. 5—SINGLE-LINE DIAGRAM OF A TYPICAL SUBSTATION LAYOUT

The oil switches on the 66 000 volt side have a rupturing capacity of 72 amperes per phase at 66 000 volts. These are adequate for the generating capacity feeding the system.

Each main transformer bank consists of three single-phase radiator-cooled units. Delta connection is used on the high tension side and star on the low, this arrangement being decided upon in order that the neutral of the 22 000 volt system could be grounded at each sub-station, a very necessary provision on a system of this magnitude. A spare transformer unit is also provided which can be promptly cut in to replace any unit that may fail. The second transformer banks have not yet been installed at the Wilmerding and Dravosburg stations, but will be put in as soon as load requirements make it necessary.

Each transformer is equipped with an oil conservator, which performs two functions. It prevents moisture from getting into the oil in the transformer and lessens the chances of oil explosion in case of transformer breakdown by keeping the transformer itself at all times completely filled with oil. It thus constitutes an important element of safety especially on outdoor transformers which are subject to wide ranges of surrounding temperature.

The conservator consists essentially of a tank mounted above the transformer and connected to the transformer through an oil pipe. This pipe enters the tank at a point considerably above the bottom of the tank, so that whatever moisture gets in settles in the bottom of the tank and can be readily drawn off. This effectively keeps the moisture out of the transformer proper. By always keeping sufficient oil in the unit to maintain the oil level at some point in the conservator, the contact between oil and air is kept entirely out of the transformer, thus reducing the chances of an explosion which might result from a flash in the transformer acting on an explosive mixture which might be formed by the oil vapor and the air above the oil level.

On the 22 000 volt side, two busses are installed, regular and emergency. Oil circuit breakers with a rupturing capacity of 12 300 amperes at 25 000 volts connect the outgoing feeders with the regular bus. The feeders can be connected to the emergency bus only through disconnecting switches, so that this bus serves mainly as a connecting link between the transformers

and outgoing feeders in case of trouble with the line circuit breakers or the regular bus. Provision has been made so that later on, if found desirable, oil circuit breakers can be installed also between each feeder and the duplicate bus. The neutral of the 22 000 volt trans-

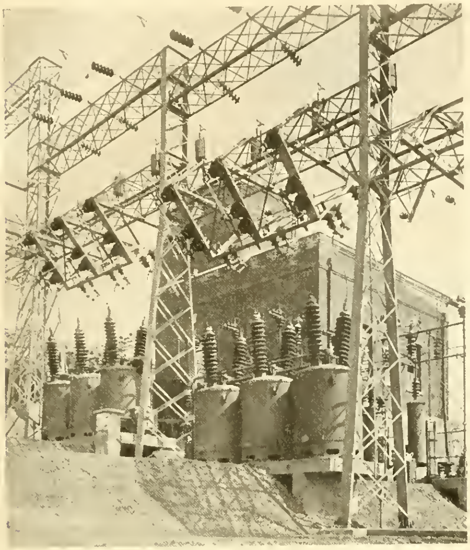


FIG 6— INSTALLATION OF 66 000 VOLT OIL AND DISCONNECTING SWITCHES AT DRAVOSBURG SUBSTATION

former windings will be connected to ground through a resistor of 15 ohms with a rated capacity of 865 amperes for 30 seconds.

All primary equipment is out of doors, mounted on substantial concrete foundations. A small brick house however, is provided to protect the switch control equipment, to house a synchronous condenser and to provide shelter for repairing the big transformers. Synchronous condensers are already installed at the Woodville and Dravosburg substations. In case of trouble, any one of the main transformers can be moved by means of a truck from its regular location into the building. Once in the building, a defective unit is protected from the weather and repairs can readily be made. Each building is equipped with block and tackle for raising a transformer out of its case.

The 22 000 volt circuits are ordinarily mounted on wood poles. Western red cedar poles are used conforming to the standard dimensions known as Class B in the N. E. L. A. specifications. Two circuits are carried on a pole, the construction being a triangular arrangement of the conductors on two crossarms with 36 inch spacing between conductors. At the top of the pole is a crossarm carrying two No. 4 hard-drawn copper ground wires mounted on porcelain insulators of 6600 volt rating. These wires are grounded at intervals of three to five poles depending on local conditions. Operating results indicate that the double ground wire is a very substantial protection to the circuit against lightning and the circuits so protected show materially less breakdowns than those protected by a single ground wire or those with no ground wire.

Requirements *c*, *d* and *e*, are met by grounding the neutral of the 66 000 volt system through resistances at both power plants and by sectionalizing the system into a number of relatively small parts connected through circuit breakers of ample rupturing capacity.

The neutral resistances at each power plant are rated at 95 ohms with a capacity of 400 amperes for 10 seconds. It was the intention to choose a value of resistance which would be low enough to prevent high transient voltages, but high enough to limit the currents flowing into grounds to such an extent that the voltage disturbances created thereby will not interfere with the operation of synchronous and other motors connected to the system. The limiting of ground currents in this manner has necessitated special relay arrangements apart from the overload relays in order to cut out the grounded sections. It is the usual experience with high-tension systems that most failures result in grounds rather than in short-circuits, so that the grounding of the neutral in this manner should prove very effective as a safeguard to service. The resistances of the above value initially inserted in the neutral

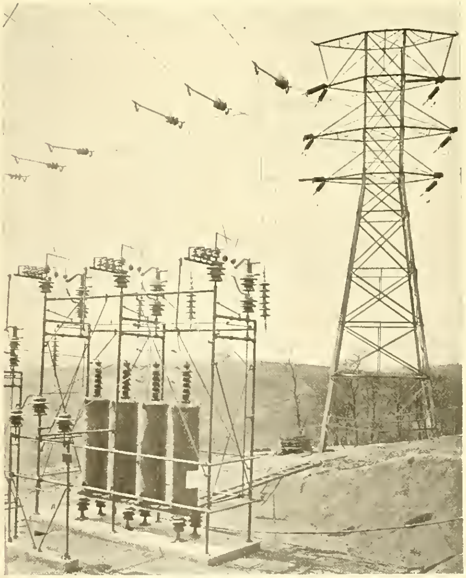


FIG. 7—TYPICAL INSTALLATION OF LIGHTNING ARRESTERS AND STANDARD TRANSMISSION TOWER

The line conductors are looped down to the lightning arrester and the choke coils are placed in a vertical position.

must be considered experimental and will be subject to change if further experience in operation indicates that some other value will give improved conditions.

Although most breakdowns are grounds, short-

circuits are bound to develop occasionally, and accordingly all oil switches have been installed with sufficient rupturing capacity to break the heaviest short-circuit which they could be called upon to open. Those at the Colfax plant have a rupturing capacity of 12 400 amperes at 66 000 volts, while those at the substations have a rupturing capacity of 7200 amperes at the same voltage. A one-line diagram of the high-tension lines and switches is shown in Fig. 10. All lines are sectionalized at the substations, and the high-tension side of each substation is divided into four parts, two bus sections and two transformer sections. The automatic protective scheme is designed to cut out any section of line or station in which trouble may develop without interrupting any other sections.

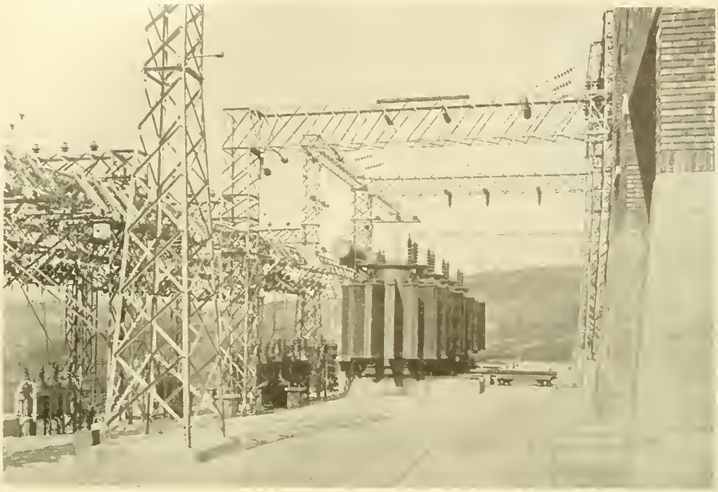


FIG. 8—TRANSFORMER INSTALLATION AT WILMERDING SUBSTATION

Each transformer is mounted on wheels and can be pushed along on its track to the car as shown. The car with the transformer is then moved to the track at the entrance of the building, and the transformer is pushed into the building for repairs.

The protection on the lines contemplates their operation in pairs, paralleled at each substation. In case of a ground or short-circuit on any section of line between substations, the circuit breakers at both ends of the defective line will immediately open, thus clearing the system of the trouble without interruption to service.

The series transformers of the two lines are balanced against each other so that under normal conditions, with each pair of lines in parallel between stations, the same current will flow in both lines, there will be no current in the relays, and all relay contacts will be open. In the control circuit, the contacts of the overload and ground relays are in parallel with each other, so that the closing of either will trip the breaker. If a line breaks down to ground the excess current due to the ground will cause current to flow through both the overload and the ground relays. This current will not be great enough to close the contacts of the overload relays. It will, however, have sufficient magnitude and proper direction to close the contacts of the ground relay which controls the circuit breaker of the faulty line. If the line short-circuits, the excess current will cause current to flow through the overload relays only. This current will be of sufficient magnitude and in a proper direction to close the contacts of one or more of the overload relays which control the circuit breakers of the faulty line. By this scheme, grounds and short-circuits are cleared by separate devices. This makes it possible to clear ground currents which are smaller than the normal load currents automatically, a very necessary condition when the neutral of the system is grounded through a relatively high resistance.

The protective arrangement for the substation bus wiring is shown in Fig. 11. It is the same as that ordinarily used to protect generator windings and leads. When the current flowing into the bus through one or more of the switches is equal to the current flowing out over the other switches, there is no current in the relays

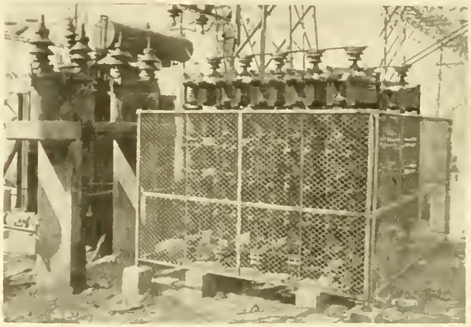


FIG. 9—TYPICAL GROUNDING RESISTANCE

A standard resistance unit for grounding the neutral of the 22 000 volt system at the substations. The resistors for grounding the 66 000 volt system are of the same general construction, but are insulated for higher voltages. Note the transformer oil conservator on the left.

and all the breakers remain closed. When, however, a failure develops, the currents flowing into the bus exceed those flowing out and current appears in the relays in one or more phases, thereby opening the two line

switches and the transformer switch, and clearing the trouble.

The transformer banks are protected in exactly the same manner as the bus sections, as shown in Fig. 12. In this case, however, an additional set of series transformers has to be placed in the relay circuit to take care of the difference in phase of the primary and secondary circuits, due to the fact that the main transformers are connected delta-star, and also to compensate for the different saturation characteristics of the 66 000 volt and

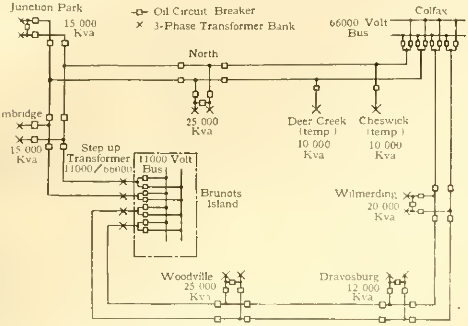


FIG. 10— TYPICAL SINGLE-LINE DIAGRAM OF THE LINES AND SWITCHES ON THE HIGH-TENSION RING

22 000 volt series transformers. If this difference in saturation was not compensated for, the transformers would be cut out on heavy overloads beyond the 22 000 volt bus. In case of a transformer failure, the circuit breakers on the high and low-tension sides of the transformer bank are affected and the high-tension tie breakers are opened.

The 66 000 volt series transformers are of the bushing type in all cases, and are mounted on the terminals of the oil circuit breakers. Separate series transformers are required for the protection of each section, so that all the terminals of both poles of the breakers carry these bushing type series transformers.

It will be seen that the entire protective scheme is based on the differential principle. Under normal conditions, no current flows in the relays, but if a failure develops, a current proportional to the failure current, is set up only in the relays controlling the breakers on the defective section. On the lines the differential principle is made use of by grouping them in pairs. This differential arrangement permits of relay settings which will allow the circuit breaker to open on failure current before such current is built up to the magnitude of an overload and without time delay. Hence, defective sections are cleared in the shortest possible time, which is of obvious advantage to the system as a whole, to the elements that are broken down, and to the users of the service.

Furthermore, any amount of current can flow between the busses of the two power plants without opening the circuit breakers on the tie lines and separating the plants. Excessive cross currents between power plants may be caused by sudden changes in load, defective governor operation, or heavy short-circuits on lines other than the tie lines connected to the power station bus. If such rushes of current are able to open the tie lines between the plants, it almost invariably happens that one plant is overloaded and the other underloaded. This causes a considerable discrepancy in the frequencies of the two plants and generally means interrupting enough additional load on the overloaded plant to get the frequency up to normal before synchronizing can take place. The very important requirement that the plants must not break apart in system disturbances as long as there is a line available between them is thus efficiently met.

The only circuit breaker on the 66 000 volt system which is set to open on overload is the one on the high-tension side of the step-up transformers at the Colfax Plant, and this is given such a high setting that it will not open except on a short-circuit at the Colfax bus.

On the outgoing 22 000 volt circuits two relays take care of overloads and one takes care of grounds. The arrangement is shown in Fig. 13.

Careful attention to the proper maintenance of voltage conditions at substations and to proper distribution of the wattless current is necessary, because the reactance of the 66 000 volt system is very high, and the voltage drop in this system is superimposed on that of the 22 000 volt and 11 000 volt systems which carry the power from the stepdown substations to the user. The high reactance of the 66 000 volt system is appreciated when it is realized that the reactance of the step up and step down transformers alone totals about 14 percent at rated loads; that under conditions of full load at 80 percent power-factor the inherent regulation at the

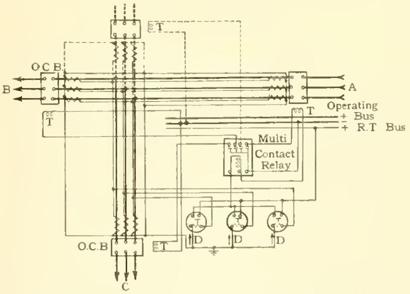


FIG. 11—RELAY SYSTEM FOR THE SUBSTATION BUS

Normal Conditions A-B=C; D=O

Fault in Bus A-B C; D O; C O relay closes trip circuits. Designed to clear trouble on the substation bus between the line switches and the transformer switch. In case of failure of the bus the currents entering are greater than those leaving and a current proportional to the difference or failure current flows in one or more of the CO relays. When the contact of one of these relays closes, the secondary circuit operates a multi-contact relay which closes the trip circuits on both the line and the transformer circuit breakers, thus clearing the trouble.

22 000 volt bus of the average substation is 20 percent; and that a dead short-circuit 20 miles from the power house on a 66 000 volt line will pull only about five times the normal full-load current of the line. Because of this high reactance, the proper handling of the watt-

less current on the system is particularly important.

To provide proper voltage conditions, large synchronous condensers are installed at the various substations and the Colfax plant is laid out for operation over a 15 percent range in voltage. At the present time 7500 kv-a condenser units are installed at the Dravosburg and Woodville Substations; at the 48th St. and Beaver Falls substations, which take practically the entire output of the North and Junction Park 66 000 volt substations; and at the Rankin station. These synchronous condensers perform the double function of regulating the voltage at the 22 000 volt substation busses and of increasing the capacity of the transmission system by raising the power-factor and reducing line drops. The increase in system capacity in this manner practically

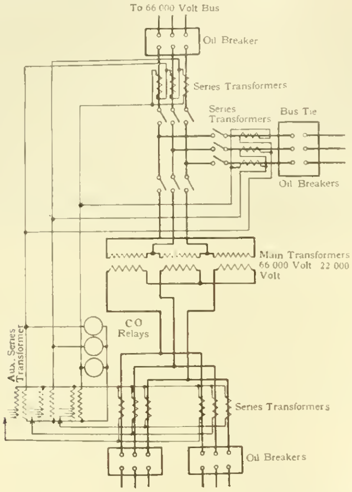


FIG. 12—RELAY SYSTEM FOR MAIN TRANSFORMER BANKS IN SUBSTATIONS

Like the bus relay system, this is a differential system which, in case of trouble in the transformers, causes a current proportional to the fault current to flow in one or more of the CO relays. When the contacts of one of the relays close the contacts on a multi-contact relay are closed, thus tripping the high and low tension transformer circuit breakers and the tie breaker.

pays the cost of the condensers, so that the voltage regulation is obtained without expense. Since voltage drop increases with the length of line and decreases with improvement in power-factor, the substations near the power plant are operated at fairly low power-factors, thereby giving relatively poor regulation, while those farthest away are kept near unity power-factor, thereby tending to offset the greater drop. This fortunately also gives the best economy of operation, and the average result of high power-factor at distant stations and low power-factor at nearby stations is to provide the most economical power-factor at the power plants, as well as to equalize the voltage regulation at the various substations.

In Fig. 14 are shown the results which can be obtained through the use of synchronous condensers in this manner. If the power factor of the load is 80 percent, Curve *d* gives the regulation which would prevail over different transmission distances, if no condensers were used. Through the proper use of condensers,

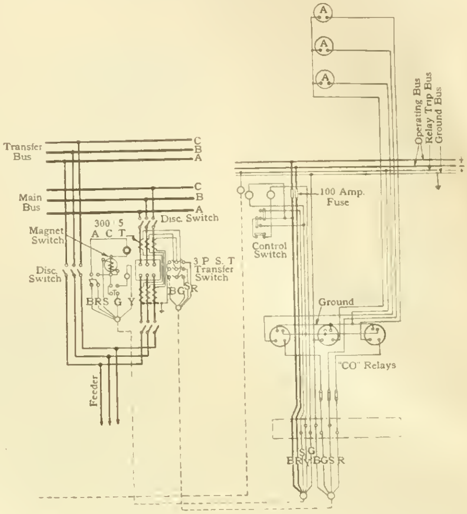


FIG. 13—RELAY SYSTEM ON 22 000 VOLT FEEDERS AT DRAVOSBURG

however, constant full load voltage can be obtained for all stations regardless of the transmission distance, as shown by curve *c*.

In order to get the voltage indicated by curve *c* the power-factor of the load must be raised to the value indicated by curve *b*. The plan contemplated provides for the same secondary voltage at all substations on the ring, and this is accomplished by the method indicated above.

The voltage at Brunot's Island is fixed, due to conditions in the previously existing transmission system and substations. The Colfax plant is designed to operate over a range of voltage from 10 500 to 12 000, which permits of the proper distribution of the wattless current between the Brunot's Island and Colfax plants.

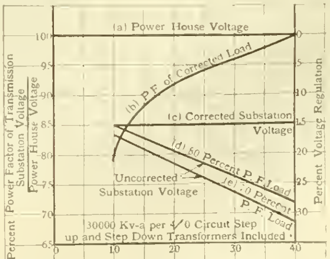


FIG. 14—EFFECT OF SYNCHRONOUS CONDENSERS IN IMPROVING VOLTAGE REGULATION

Variation of the Colfax voltage in conjunction with the synchronous condensers is also of use in maintaining the desired voltage at the substations. When operating two power plants in parallel over a high reactance

transmission system, the proper distribution of the wattless current becomes a very important element, since if either plant is required to carry more than its share of the wattless, it may be necessary to run additional generating capacity to avoid overheating. The provisions for voltage adjustment above referred to will adequately take care of this situation. Standard voltage regulators are installed to regulate the bus voltage at the Brunot's Island and Colfax Power Stations and at all substations where synchronous condensers are located.

It has already been pointed out that reliability of service was a prime consideration in the design and construction of this transmission system. It is believed that with the simple and rugged construction of lines and stations, extra heavy installation throughout, high capacity circuit breakers, spare equipment at all points, adequate protective features including ground resistance, lightning arresters, complete relay system, and multiple transmission routes for delivering power into the district served from both main power plants, this transmission system typifies the highest development of the art at the present time, and will render to the district served an electric power service thoroughly reliable and fully adequate to meet the exacting demands that will be made upon it.

Power Requirements in the Pittsburgh District

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PITTSBURGH is located at the confluence of the Allegheny and Monongahela Rivers which forms the Ohio. It is the financial, educational and social center of a great industrial district, tributary to each of these navigable streams for a distance of more than 50 miles, within whose boundaries are located over 100 different municipalities. This district, with an area of approximately 1000 square miles in Allegheny and Beaver Counties, with an aggregate population of about 1 300 000, is known as the Pittsburgh District, and is served by the Duquesne Light Company.

Its pre-eminent position as an industrial district is due to its favorable location, natural resources, ideal climate and transportation facilities. There are available over 80 miles of excellent harbor sites, affording cheap water transportation leading direct to the Gulf of Mexico, the Panama Canal, and the ports of the world. The Federal Government now has under way a very extensive improvement of the Ohio River which, when completed, will eliminate the obstacle of slack water and render possible barge shipments of coal and other products at all seasons of the year. Also, the district has exceptional rail transportation service, as six railroads with many branches radiate from the City of Pittsburgh in all directions, reaching every section of the country. Furthermore, it is traversed by several interurban lines affording transportation between many of the municipalities in the district and the City of Pittsburgh. Some idea of the magnitude of its industrial activities and the extent of its natural resources may be gained from the fact that there are over 2600 manufacturing establishments engaged in over 250 different lines of production, so diversified as to embrace almost all the commodities for which the commerce of the United States is famous.

Within a radius of 40 miles the production is on such a vast scale as almost to stagger the imagination. Statistics show that manufacturers of the United States are dependent upon this region for 45 percent of their raw materials for agricultural implements, hardware products and automobiles. In terms of the production of the United States, the district produces nine percent of the bituminous coal, 24 percent of the pig iron; 50 percent of the crucible steel; 28 percent of the finished rolled iron and steel products; 60 percent of the tinplate; 65 percent of the glassware products; and possesses 20 percent of the Bessemer converters and 35 percent of the open hearth furnaces. The annual tonnage of this vast production is two and one-half times greater than that of New York, London and Hamburg combined, both before and after the war. The value of production in Allegheny County for the years 1916-1919 is shown in Fig. 1.

Compared to the industries of the world, the district numbers among its industries the largest structural steel plant; the largest glass manufacturing plant; the largest independent wire manufacturing plant; the largest air brake manufacturing plant; the largest corporation manufacturing rolling mill machinery; the largest pickling and preserving plant; the largest radium and vanadium plants, and the largest cork manufacturing plant.

Pittsburgh is the center of an immense jobbing trade supplying over ten million people and producing an annual business surpassing the billion mark. It is the third city in the country in the distribution of produce. It is the strongest financial community in the country, with a banking surplus of $100 000 000, which is exceeded only by New York and Philadelphia, with banking deposits per capita larger than any other city in the United States, and with bank clearings greater than Cleveland and Cincinnati combined. The average per capita wealth of the district is over $2500, and the daily payroll exceeds two million dollars, while the total production, valued at around two billion dollars annually, is greater than that of each of 21 states of the Union.

Consequently, new industries are rapidly locating in this district, where necessary raw materials are produced; where manufacturing machinery and tools are exempt from taxation; where there is an abundance of skilled labor; and where there are many desirable sites available from the standpoint of shipping, housing employes, and an adequate and dependable supply of power, which

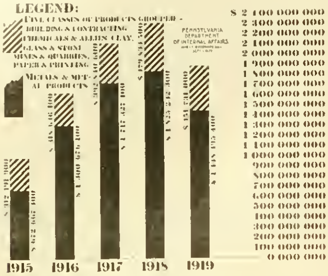

FIG. 1—VALUE OF PRODUCTION IN ALLEGHENY COUNTY FOR THE YEARS 1915 TO 1919

can be obtained from the ring transmission system of the Duquesne Light Company encircling the district.

With the development of industrial activity in the district, the load of the Duquesne Light Company has increased from 8000 kw in 1898, to 320 000 kw in 1920. The amount of this increase in connected load annually from 1913 to 1920 is shown in Fig. 2, together with the yearly increase in the number of customers and kilowatt-hour output during the period. Prior to 1913, this growth was due in part to the consolidation of several companies; the conversion to central station service of numerous isolated plants, and the natural growth of the community served. Since that time, the growth has been entirely due to the replacement of isolated plants with central station power and the normal increase in the power requirements in the district. The consumption per capita during this period has more than doubled, so that for 1920 it had reached 665 kw-hrs.

During this time the Company has been very successful in replacing with its service a great number of isolated plants which found that they could no longer generate their power as cheaply as they could purchase it. This has been due largely to the increased costs of fuel, labor and maintenance. Due to the conditions created by the war such plants were able to dispose of their equipment satisfactorily and invest the proceeds in the production requirements of their business. There were others who were confronted with a limited space, which it was found desirable to convert to productive capacity—an important item to consider in the cost of generating power.

The application of electric power for industrial heating, as exemplified by the electric furnace and electric oven, has had a phenomenal development in the district. This is indicated by the fact that twenty-three electric steel and alloy furnaces have been contracted for, a load totalling 33 000 kw, of which seventeen have been connected, representing a load of 22 000 kw and a consumption of about eight percent of the total power generated by the Duquesne Light Company and comprising six percent of the total number operating in the United States. For the melting of brass three electric furnaces have been contracted for, giving a 500 kw load. There are many installations of ovens for electrical heat treatment of steel and enameling, which process is especially satisfactory on account of the accurate control of temperatures and atmospheric conditions desired.

The domestic business has been particularly flourishing as the result of wiring many old houses and the increased use of household appliances, which have not only been a great convenience, but in many cases have actually been the means of solving the domestic servant problem.

The total power requirements of the Pittsburgh Railways Company, operating street cars in the City of Pittsburgh and several interurban lines to nearby cities, are furnished by the Duquesne Light Company.

The municipal and rural lighting load has greatly increased, due to the demand for improvement in the lighting of streets and highways, which resulted in the replacement of gas lighting by electric lighting, the former having been used to a greater extent than in most cities on account of the abundance of natural gas available in this territory.

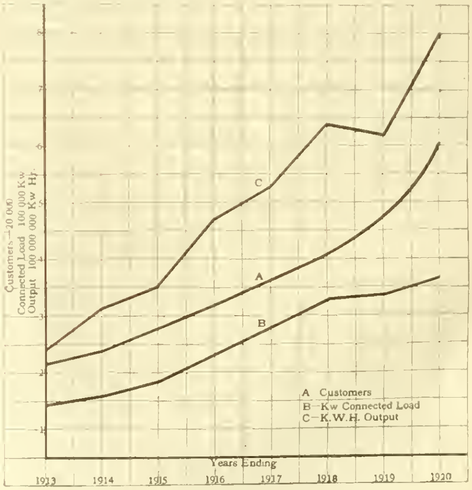

FIG. 2—INCREASE IN NUMBER OF CUSTOMERS, CONNECTED LOAD AND KW—HR. OUTPUT FROM 1913 TO 1920

Of the total kilowatt-hour output of the Duquesne Light Company as shown in Fig. 3, 56 percent is distributed for power; 26 percent to street railways; 8 percent for mercantile purposes, 4 percent for street lighting, 4 percent for domestic use, and 2 percent for miscellaneous work.

The industrial and commercial requirements of the district, both those served by the Company and those

generating their own power are shown in Fig. 4. All of this power load generated by isolated plants is considered to be prospective business for the Company, with the exception of that generated by the blast furnace byproduct gases. With the increased require-

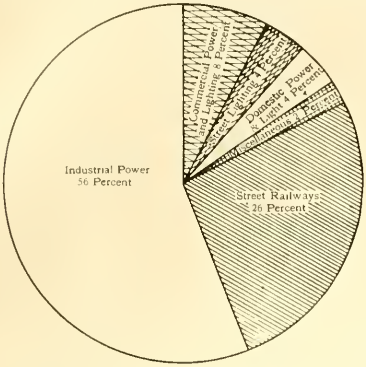

FIG. 3—PERCENTAGE OF OUTPUT OF DUQUESNE LIGHT COMPANY DEVOTED TO DIFFERENT CLASSES OF SERVICE

ments for power in such plants, there is a possibility of the byproduct fuel not being sufficient, thus necessitating the use of coal or other fuel. Under these conditions, it may be advisable to purchase all power beyond that which can be produced by the use of waste gases. Mutual arrangements between the steel companies and the Duquesne Light Company, whereby the latter would furnish all power except that produced by waste gases, would be most desirable and would give the steel companies reliable power at reasonable rates and the Company a load of excellent factor.

Even where blast furnace gas is available there are cases where the purchase of all power from a central station may prove of advantage. As these gases possess very low heat values and cannot be transmitted any great distance with economy, it is impossible to collect them from scattered sources in one central location where a large plant could be erected. The cost of the generating capacity which would be necessary for utilizing this gas in relatively small units would be excessive, and refinements of operation and efficiency would be limited in comparison with that of such a station as the Colfax Plant of the Duquesne Light Company, whose sole business is the generation and distribution of electric power.

Referring to the metals and metal products classification, by far the greater portion of the isolated plant load exists in steam-driven steel rolling mills. The increased cost of operation due to the increased price of coal, and the disadvantages of steam drive, as compared to central station motor drive, where speed regulation and control permit greater production and better quality of products, is generally recognized. The remainder of the load represented in this classification consists of many diversified industries whose power needs are being rapidly supplied by the Company. This is due largely to keen competition, necessitating the installation of modern motor driven equipment in such factories to speed up production and reduce costs to meet competitive conditions.

There are about 20 000 kw of isolated water pumping stations in the district. These consist largely of various types of steam-driven equipment, which should be replaced by electric-driven equipment, when the present facilities become obsolescent to the extent of the change-over cost being more than offset by the economy effected by the use of purchased power. While it is realized that these plants have an extremely high load factor and in most instances a good pumping economy, yet it is hardly possible for this economy to equal that obtained with electric-driven centrifugal pumping installations supplied with power by the large efficient units in use by the Company. This is especially true with installations having an adequate reservoir capacity so that the pumping could be done during the off-peak hours of our system. Such an arrangement would permit of a lower rate than that to a power user requiring continuous service during the peak-load period.

To completely electrify the railroads operating in the district, it is estimated that approximately 200 000 kilowatts of capacity will be required. It is understood that some railroads have already made tentative plans for partial electrification. This load is prospective business for the Company, as it would be relatively

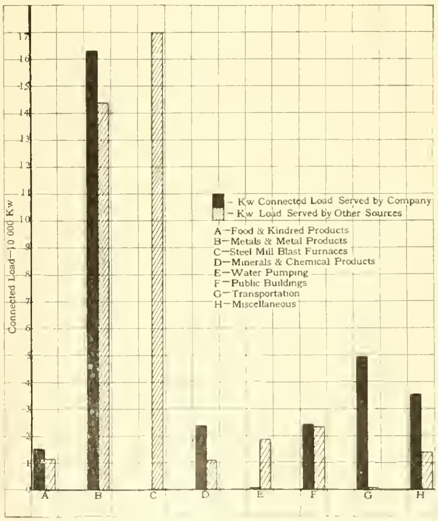

FIG. 4—CLASSIFIED POWER REQUIREMENTS IN THE PITTSBURGH DISTRICT

uneconomical to generate it in plants built only for that purpose, because of the lack of diversity in a load of one character. Such a load would be an advantage to the central station, where there would be considerable diversity between it and the industrial load which now

comprises the larger portion of the Company's output.

The present electric furnace load of 22 000 kilowatts supplied by our Company and representing eight percent of the total kw hrs. output, is considered to be just the beginning of the development expected within the next few years. The electric furnace has earned a permanent place in the steel industry for producing high grade tool and alloy steels and steel castings. It has supplanted to a large extent the crucible process in the production of tool and alloy steel due to its lower cost and greater flexibility. The demand for these steels is constantly increasing, not only because new users have been found for them, but because of their demonstrated superiority, especially in the automotive industry, which is becoming increasingly dependent upon tool and alloy steels.

In the production of steel castings, it has been found that, due to the intense heat of the electric arc, the absence of the contaminating effects of the combustion gases and the reducing atmosphere within the furnace, it is possible rapidly to melt and refine a product superior to the highest grade of casting made either in the open hearth or crucible furnaces. At the present time, many large consumers of steel castings frequently specify the electric steel for their more important work, for which they formerly had been content to use converter or open hearth steel.

While the electric furnace has been used principally for the production of tool and alloy steel and steel castings, it is becoming more extensively used in the production of gray iron and malleable castings. In the manufacture of especially sound and fine castings of light and thin section, it is a worthy competitor of the old cupola process. The demand for high grade iron castings is increasing, and the indications are that those made by the electric process which, in many instances, have been produced at a lower first cost and with fewer returns of defective castings, will sell for maximum competitive prices.

To promote the rapid industrial expansion of the district by furnishing an abundance of economical power, the Duquesne Light Company has erected its Colfax power plant, which is the highest attainment in the art of generating electric power. This plant is designed for an ultimate capacity of 300 000 kw, and is located on the Allegheny River, about sixteen miles above the City of Pittsburgh. Coal is brought to the plant from the Company's mine over its own railroad, thereby relieving the congestion of transporting coal on the other railroads in the district. By the closing down of the isolated plants in the district the railroads will further be able to utilize their equipment for the shipping of manufactured products. This will eliminate many smoky chimneys in the district and, with the electrification of railroads, will result in the City of Pittsburgh being referred to not only as "The Workshop of the World", but also as "The Electrical Workshop of the World."

The Power System of the U. S. Steel Corporation in Pittsburgh

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THE interconnected group of plants of the United States Steel Corporation in the Pittsburgh district, consisting of Homestead Steel Works and Carrie Furnaces, Edgar Thomson Steel Works and Furnaces, and the National Works of the National Tube Company at McKeesport, make a power development of considerable magnitude, which will probably never be replaced by the purchase of power from the local commercial central stations.

The Carrie Furnace plant is an integral part of the Homestead Steel Works and so may be considered as one unit. The plant at Carrie Furnace supplies a large amount of power to the Homestead Steel Works, in addition to furnishing about 11 000 kw to the Universal Cement Company's plant at Universal, six miles from the furnaces.

The stations at Carrie Furnaces, Edgar Thomson and Duquesne are based on the use of blast furnace gas,—an unavoidable by-product, which must be used close to the point of origin on account of its low calorific value. For the purpose of this article we can assume that for each ton of pig-iron, by product gas containing 14 000 000 B.t.u.'s of latent heat will be produced. Of this we can expect 30 percent to be used to heat stoves, 20 percent to be used for furnishing the blast, and 10 percent for miscellaneous purposes around the blast furnaces, or a total of 60 percent required at the furnaces themselves. We can safely estimate, then, that 40 percent of this heat will be available for power production, which, if all converted into electric power on the basis of 21 000 B.t.u.'s for each kilowatt delivered to the switchboard, would make 266 kw-hrs. available for each ton of pig-iron produced.

In running through the different losses and additions which are encountered between the production of one ton of pig-iron and the finishing of one ton of steel, we can fairly estimate that one ton of pig-iron produced will represent one ton of finished steel shipped.

From data available we can estimate that it will not require in excess of 120 kw-hrs. per ton of finished steel

in the shape of sheet bar, small billets, sheared plates, structural steel, rails, etc., and not over 150 kw to carry the finishing down as far as merchant bar. The 266 kw-hrs. is based on a production which is spread over 365 days in the year, and the rolling steel would only be distributed over 300 days in the year, so that the power immediately available at the time it is required would be reduced in the ratio of 300 to 365, which would show 218 kw-hrs. available for each ton of material to be finished. This figure, compared with the maximum shown above, would leave 68 kw-hrs. over actual requirements, or 45 percent surplus to take care

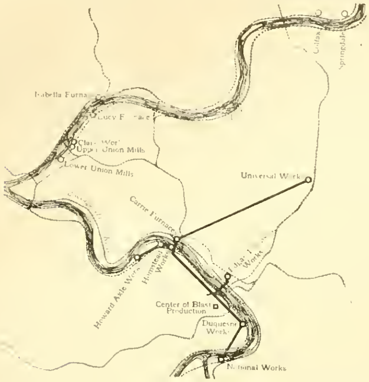

FIG. 1—LOCATION OF POWER PLANTS AND TRANSMISSION LINES

of peak loads, which should be ample for the size of stations required by a completely electrified mill and the probable diversity factor which they would have.

It will be seen, therefore, that it is possible for a blast furnace and steel plant to be practically self-contained as far as power production and consumption is concerned, making the purchase of outside power unnecessary.

The present generating capacity of the stations referred to is as follows:—

Homestead Steel Works	5 350 kw
Carrie Furnaces	30 150
Edgar Thomson Steel Works and Furnaces	11 275
Duquesne Steel Works and Furnaces	28 175
National Tube Works	16 875
Total	100 825 kw

Of this total, 14 250 kw is 250 volt direct-current, and 86 575 kw is generated as 25 cycle alternating current at 6600 volts. Of the total, 23 700 kw is equipped with gas engines as prime movers, 15 250 kw is steam engine driven, and the remaining 61 875 kw is steam turbines.

As all of these stations are within a few miles of each other, it was considered advantageous to tie them together so that they could support one another, thus reducing the amount of spare equipment required, and giving additional safety in case of trouble in any one station. The present transmission lines between Duquesne, Edgar Thomson, Carrie Furnaces and Homestead consists of two parallel independent three-wire circuits, as shown in Fig. 1, one of 500 000 circ. mils and the other of 400 000 circ. mils, carried on steel towers, steel poles and wooden poles, as conditions require, and insulated for 6600 volts. Insulating for 6600 volts under these conditions does not necessarily mean the use of 6600 volt insulators, and it has been found desirable to use 25 000 volt insulators in many places on the line and 40 000 volt insulators in some exceptionally smoky and dusty places in running through the mills. These tie lines are all overhead open construction with bare copper cable, carried on pins and wooden cross arms. A double bus arrangement is used at the Duquesne, Edgar Thomson and Carrie Furnace plants which, in conjunction with the two circuit tie lines and relays that are used between the stations, forms an extremely flexible combination, so that line troubles or other disturbances produce a minimum interruption of service.

The connecting line between this group of plants, and the National Tube Works at McKeesport consists of a 4/0 three-wire aerial cable, steel armoured but without lead covering, and is insulated for 25 000 volts, in view of the possibility of stepping this line up to 22 000 volts in the future.

All the plants referred to so far are connected directly from the bus-bars at 6600 volts, 25 cycle as generated in the stations, without the interposition of any step-up or step-down transformers.

The line connecting the Carrie Furnace plant with the Cement Plant consists of two parallel independent three-wire circuits of No. 0 copper wire, carrying 25 cycle current at 23 000 volts through step-up and step-down transformers at each end of the line.

Water Power Developments

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Consulting Engineer
Madison, Wis.

CONSIDERABLE misunderstanding seems to exist as to the proportion of the water power resources of the United States now developed and also projected under the new Federal Water Power Act. All estimates of potential water powers of the United States that will admit of practicable development must be very uncertain, first on account of the lack of detailed knowledge of the topography of the river valleys and of information as to available dam sites and consequently of the actual head that can be developed; and second, because of the lack of knowledge of available stream flow. For these reasons such estimates must be only roughly approximate, and until more detailed information is available it is sufficiently exact to estimate the power of the rivers of the United States at about 30 000 000 horse-power (on a 24-hour basis) and the power which can be developed on the basis of "the average minimum flow for the average maximum six months" at 60 000 000 hp (on a 24-hour basis). This last quantity would probably require, on the average, that from 15 to 20 percent of the power be developed from auxiliary sources, in order to maintain the full power every day and hour for each year.

If we accept the figure of 60 000 000 24 hour horse-power as the probable maximum potential water power resources of the United States which appears at all practicable of development, we must appreciate also the terms in which the estimate is expressed in order to comprehend these national resources fully. Little power is used uniformly 24-hours per day. In most cases when power is used for manufacturing purposes, the maximum load occurs within the working day and, when used for general light and power purposes, the maximum load occurs during the day and evening. Mr. Philip Torchio estimates the total steam power installed in the United States, including central station, manufacturing, steam railroads, steam vessels, mines, and quarries at 96 000 000 horse-power and the total power output at 145 200 000 000 horse power-hours per annum. This total output could be generated by a 16 000 000 horse-power installation working uniformly 24-hours per day for the entire year, hence the actual load factor averages about 17 percent. Mr. Torchio also estimates the hydraulic horse-power, installed at the date of his estimate, at 8 000 000 horse-power and the hydraulic power output at 29 000 000 000 horse-power-hours, with a load factor of about 41.5 percent.

It is probably conservative to estimate that the average water installation can be developed to utilize its full power on a 50 percent load factor, and hence to conclude that the present water power developments in the United States are utilizing the ultimate hydraulic resources to only one-half of their turbine capacity.

At the beginning of 1920 it was estimated that the water power development in the United States was as follows:—

	Horse-Power Developed	Percent of Total Development
New England States......	1 506 520	15.3
Atlantic States	2 052 840	30.1
Central States	2 600 200	27.5
Mountain States	1 111 990	11.3
Pacific States	1 551 000	15.8
Total	9 823 540	100.0

In estimating the undeveloped potential water powers of the United States, the total developed power as above stated is commonly subtracted from the estimated total potential water power with the result that the undeveloped power is estimated at about 50 000 000 horse-power. It will undoubtedly be much nearer correct if the developed power be estimated on a 50 percent load factor, which would raise the estimate of undeveloped water power to about 55 000 000 horse-power or, in greater detail, as follows:—

	Potential Horse-Power	Percent Developed	Undeveloped Horse-Power
New England States..	1 951 000	38.6	1 197 750
Atlantic States	9 348 000	15.8	7 871 580
Central States	7 360 000	18.3	6 010 400
Mountain States	14 851 000	3.9	14 204 000
Pacific States	25 850 000	3.	25 074 520
Total United States	59 360 000	8.3	54 448 220

It is understood that the applications filed under the new Federal Water Power law amount to 13 500 000 horse-power. This has been estimated at about 27 percent of the total water power resources of the United States. While information is not available as to the basis of these proposed developments, it is unlikely that they will be developed on lines greatly different from those already developed; hence they should be estimated on the basis of a 50 percent load factor and at about 13.5 percent of the total water power resources of the United States. It should therefore be noted that even if these powers should all be developed they would raise the developed power of the United States to less than 22 percent of the total water power resources.

There is therefore still available, undeveloped water power for which no applications have yet been filed amounting to about 78 percent of the available water resources of the United States, or to about 47 000 000 24-hour horse-power.

The development of these water power resources is of great importance to the nation, and those who undertake judicious developments should be encouraged in every proper way, by the enactment of liberal laws and by the guarantees of liberal and at least reasonable rate control. These developments will involve the investment of billions of dollars in construction, and additional billions in collateral industries and improvements.

They will accomplish either the saving of millions of tons of coal now annually consumed in power plants or an equivalent saving in fuel that would otherwise be consumed. They will afford a source of power not contingent on strikes or transportation blockades, and therefore more dependable and assured.

The collateral increase in property values, and in population, which will necessarily accompany these developments, the conservation of millions of tons of fuel for future generations, the substantial development of the states and the immediate localities in which these developments take place and the betterment of industrial and living conditions resulting from such development are public benefits which will warrant the most liberal treatment of those who undertake such projects. To secure these developments, their projectors must be assured of the possibilities of rewards for their endeavors commensurate with the risk involved and the public must be made to realize the difficulties surrounding their profitable development.

TABLE I—PERCENTAGE OF POWER USED, COMPARED WITH POTENTIAL WATER POWER

States	Percent Power Used	Percent Potential Water Power
New England	12.8	2.98
Middle Atlantic	27.8	4.62
East North Central	23.4	2.98
West North Central	6.8	3.63
South Atlantic	9.7	7.90
East South Central	4.9	3.64
West South Central	4.5	1.52
Mountain	3.0	20.92
Pacific	7.1	42.81
Total	100.0	100.0

Most of the profit made in water power developments up to the present time has been through the financing of such properties rather than in their ownership and operation. It is safe to assume that at the present time there are few water power owners or owners of water power securities that are making a profit even fairly commensurate with the risk involved by their investments. On the other hand, to secure the financing of such development requires a degree of security and a possibility of profitable returns which is not common in the undeveloped water power projects of today, and many of the projects for which applications are now pending under the new federal law will undoubtedly find the financing of the installation the most serious factor to overcome.

One of the greatest difficulties in the way of the rapid development of water powers lies in the distance of the points of development of such powers from the markets where power is needed. Sixty-five percent of all the power used in the United States is east of the Mississippi River and north of the Ohio River and the southern Pennsylvania boundary, where only about ten percent of the potential water powers are located. About 73 percent of the potential water powers are in the Mountain and Pacific States where only about ten percent of the power market is now located.

The general distribution of power demand and possible water power available are shown in Table I, which is, however, somewhat misleading, from the fact that many of the water powers estimated for the districts where most of the power demand is located are inaccessible to the manufacturing centers under present conditions of commercial and manufacturing development and under the present developed methods of power transmission.

The development of a water power is not a simple method of surely capitalizing the waste energy of the streams and securing the returns. The hazards involved, both in the construction of such properties and in the contingencies of their operation and maintenance are considerable. With the advent of electrical transmission coupled with the popular conception that water powers were always exceedingly profitable, and that by means of such developments the waste energy of water could be advantageously turned into dividends, investors eagerly sought water power investment. The expected results have seldom been realized and the actual results have sometimes proved disastrous. An extended list of financial catastrophes that have resulted from this conception of water power development could readily be made. Foreclosures and sales of water power properties have been common. In one case, the investors in the bonds of a water power company realized less than five percent of their par value. In another case, the plant was abandoned and dismantled. It is, of course, apparent that such projects were ill-advised and should never have been undertaken or, if attempted, undertaken on a more conservative basis; but the history of every business is full of investments of this character, and no line of business has ever been developed in which the path of such developments has not been strewn with the wrecks of ill-advised projects. No man is, or can be allwise, and a question as to the ultimate success must accompany almost every new endeavor, and throw a doubt on the wisdom of its projectors and on the desirability of the investment. This is essentially true in all water power developments.

Few will agree with the statement of a prominent water power engineer before a committee of the House of Representatives that, "Today the matter of developing power from falling water is a matter of absolute engineering certainty." Such statements are misleading for, while experience can reduce hazard and increase security, it can never obviate the contingencies of floods and unforseen physical conditions or the uncertainties of costs of construction and of market conditions.

While it is perfectly true that the best engineering practice in water power design has reached a fairly high stage of development, compared with former practice, it is equally true that many engineers engaged in this work have failed to keep pace with this progress, and many designs offered are open to serious criticism, as not affording a proper basis for adequate, safe and profitable development.

Plans for large and important structures are rarely devised that do not require more or less modifications during construction. Unless this fact is duly appreciated by the designer, and liberally allowed for in the estimate of cost, such estimates have often been found more or less inadequate to complete the structure. The hazards of construction increase with the difficulties. When a structure is built in and across a river, the work of construction is subject to unusual hazards, which cannot always be foreseen. Due to conditions which cannot be fully predetermined without unwarranted expenses, and to the contingencies of flood, the amount of investment is not easily determined and the ultimate cost is frequently greater than any reasonable estimate that can be made.

The unexpected extra costs of such developments due to unforseen delays is often serious. The interest on bonds must be met semi-annually or annually from their date of issue; hence, interest during construction and during the period of market development is an important item which is particularly uncertain in water power development. In a recent development of this kind, a flood the most extraordinary that had occurred on the river within the known records not only caused a loss of approximately $40 000 to the work under construction, but was followed by continuous and unusual high water for the year following, so that not more than 90 working days were available within the year. In the same endeavor, an ice jam in the spring carried out all the trestle and false works, involving a loss of perhaps $10 000 more. These casualties created a delay of more than a year, with an extra interest cost of $100 000.

Such hazards are more constantly present in all classes of hydraulic endeavors than in those of almost any other kind of developments. While care and experience with water power projects may perhaps finally result in greater consideration and more liberal estimates, so as to provide for contingencies which are likely to occur, still the contingencies exist, and such investment will, in the future as in past, be frequently underestimated, and the actual costs of construction will require greater investments than the projectors will think possible, even when money is judiciously expended.

Even after a plant is once constructed, the contingencies are not removed. Within the last few years a flood in one of our rivers caused a loss of about $300 000 to a single development. This loss resulted from an extraordinary condition which could hardly have been foreseen, and which would probably not have occurred once in a thousand times under similar conditions. In another case a dam was seriously injured by a flood produced by the destruction of another dam built by a different engineer, long after the first dam was constructed. The dam injured possessed sufficient strength and capacity for all contingencies of normal flow that were liable to occur, yet the unexpected destruction of another structure afterwards built above it, caused an extraordinary condition that resulted in a loss of perhaps $150 000 and put the plant out of commission for more than a year.

Numerous instances could be recited where either fundamental defects or extraordinary conditions have destroyed or seriously injured dams and water power plants and caused serious losses to their owners. Mankind is fallible; our knowledge of the possible activities of natural forces is limited; the effect of the possible combination of all of the known and unknown factors can never be clearly seen or appreciated; yet these contingencies are ever present, and must be considered by water power designers and investors.

A water power can seldom be developed at a first cost which compares favorably with the cost of a plant developing power by heat engines. If a water power company is an independent concern which develops its source of power to the "average minimum for the average maximum six months" and at the same time must supply the market demand for power at all times, it must install an auxiliary heat engine plant to develop power at low water stages. Sometimes, such an auxiliary plant must have a capacity almost as great as that of the water power plant itself. The cost of such an auxiliary power development must be added to the cost of the water power development.

A steam plant can always be constructed of a size proportional to its prospective market and the plant can be increased and enlarged as the market demands, to any extent and without over investment. A water power to be economically developed must practically be developed to a certain capacity regardless of its market. Powers on large rivers can seldom be developed and operated successfully in a small way. On a given river it is almost as expensive to develop a small amount of power as to develop the stream to its capacity. Essentially the same dam with the same appurtenances are necessary, whatever the capacity of the development. The same operating force will usually be required whether the plant is fully or partially loaded, and whether the development is partial or complete. If the power is transmitted, the same towers required for a certain capacity will carry twice the capacity or more equally well. The completed development will involve a larger power house, a few more turbines, generators and equipment, somewhat larger transmission wires, but these are usually the only extra expenses involved. Hence, on large streams, the development must be sufficiently large to pay, and can be made to pay only when an adequate market is available and an adequate load is secured. The investments in such plants are so great that they can never be built except for a market already developed, at least for their principal load, unless industries are developed in connection with them. Both fixed charges and operating costs begin at once when the plant is constructed, and interest starts with construction. A market must be obtained almost immediately on completion of the development in order to meet expenses, or the plant will go into bankruptcy.

The public, including all consumers of power

generated by such a plant, will from necessity receive a portion of the benefit from the use of such power from the commercial conditions that follow its development. As a rule, a water power company must supply power to a market partially, at least, supplied with power from some other source. Investments in power generating machinery of some kind have already been made. Fixed charges have already been incurred, and the water power company finds that in order to introduce its product, it must sell power below the station cost of producing it by means of steam plants, and not on the basis of fixed charges plus operating expenses of the hydraulic plant. Only in cases where the market developed is entirely new, and where no fixed charges have been entailed for previous power plant installations, can a water power company hope to realize from the sale of water power, even a part of the fixed charges of the steam plant. Even under such conditions, a material reduction must be made in order to induce customers not to install isolated plants of their own for the production of such power, but to purchase the power developed from the water power plant.

While an undeveloped market may ultimately result in a greater unit price for power, the development expenses (unearned dividends on capital invested, unpaid interest on securities, and unearned depreciation charges) will so increase the cost of developing a profitable business as to make the financial success of the project at least questionable. Therefore, it is essential for the success of even water power developments of medium size that an available market shall be within transmission distance, even though the resulting power prices will necessarily be reduced.

If a direct combination can be effected between the water power company and a steam electric company already doing business in such market, the steam plant may be utilized as an auxiliary to the water power, and the whole value of the output utilized by the combined interests. Such a combination is usually the only way in which a reasonable net profit can be obtained from water power development. The best results can be obtained only by combination with an industry or market already developed, in which the power can be utilized at its true market value.

Ordinarily, it is a comparatively easy matter for an operating industry that is showing fair returns on the investment to secure the amount of money necessary for reasonable expansion or for its current business. The problem of financing a corporation whose property and business are both a matter of future development, and necessarily more or less speculative, is a very different matter. By "speculative" is meant any investment dependent for its success upon the development of a future productive business of any kind, whether it be the manufacture of mercantile products or of power, the success of which depends upon the judgment of men more or less familiar with the business or expert in such developments.

Before a reputable investment house will undertake the financing of such an enterprise and endorse it with the prestige of their name and reputation, guaranteed by the great care they have previously exercised in financing such properties, the project must be carefully examined by experts of reputation, men who are of the highest ability and experience, who can and will vouch for the technical features of the construction, for the expense involved, for the market available, for the legality of the enterprise and in fact for its probable complete commercial success. Such houses will not lend their assistance to a project of this kind without fair returns both for themselves and for their clients.

The securities issued for the development of water power properties are usually bonds, preferred stock and common stock.

Bonds and preferred stock represent the actual cash investment, and common stock represents the speculative element or prospective profits over and above the market cost of money. The security of bonds is increased when they represent only a part of the actual investment and when there is an equity represented by an actual cash investment, which may be in the form of preferred or common stock. The public will not be induced to invest in such bonds at only a moderate rate of interest without some form of stock bonus; that is, without a share in the prospective profits.

If a stock bonus can be obtained with such a bond, it will give the purchaser a chance not only of increased return but of increased capital value, and such an investment at once becomes more attractive. On the other hand, a rate of interest on bonds issued on speculative industries sufficiently high to induce the public to purchase such securities, may be fatal to the success of the project.

Interest on bonds must be met promptly each interest day to avoid foreclosures, while stock must await actual earnings for its dividends. On account of the necessary payment of interest on bonds, many corporations have found it impossible, in the face of unexpected difficulties and delays in construction, and the delay in developing a market, to meet fixed charges and operating expenses, and end in failures when, if they could have been financed with fewer bonds, or bonds at a lower rate of interest, and thus been able to delay dividends, they would have been able to survive and have been ultimately successful.

Common stocks always represent the speculative feature of an investment, even when fully paid at par value. They are sometimes the only securities issued and share in the net profit of the venture. While they are always junior to preferred stocks and bonds, they represent, through their majority holders, the business management of the project.

The great advantage to a company of capital raised from stock is due to the consequent reduction in fixed interest charges. The development of a market commonly takes a considerable period, and unless a

company can earn at once fixed charges and operating expenses, a considerable amount of extra capital must be provided above the cost of construction to carry the venture beyond this period and place it on an earning basis.

In the case of water developments, bonds bearing five or six percent interest cannot, even under normal conditions, be made acceptable to the purchaser except at a large discount, or by a gratuitous distribution of junior securities representing the speculative side of the project. Such bonds can, however, usually be sold at a comparatively low discount if, in addition, the buyer receives a junior security which may possess a value and an earning capacity, if the project is successful.

Take for example, a water power project financed on this basis, where the cost of construction and financing will be approximately two million dollars. If, in addition to the bonds amounting to this total sum and bearing, say, five percent interest, a speculative stock (which represents prospective profits, or water power rights and privileges) be also issued in the same amount, investors will often take such bonds or securities at a reasonable price from a responsible and experienced financial house, if they also receive as a bonus say 50 percent of speculative stock. Where care had been taken, the bonds may be a reasonably safe investment. If the junior securities or stock should ultimately pay ten percent, the net result to the bond purchaser would be ten percent on the actual total investment, which is certainly no greater return than should be earned by bond holders in such a hazardous investment.

The projectors of the scheme, or the parent company, usually base their entire hope of reward for their endeavors in such projects, on such portions of the stock as they are able to reserve from the cost of financing. They borrow the capital on their property and credit and, with the bonds representing a first lien and fixed returns, they give such proportion of the stock as the market demands.

If the projectors, or the stockholders of the parent company, make an actual investment in the junior securities or stock, thus placing the primary securities on a sounder basis by virtue of an equity in the work of 50 percent or more, the primary securities or bonds can sometimes be sold at a low discount without a stock bonus. In such a case, however, the stockholders have invested their money in a security which is secondary to the bonds issued and which involves most of the risk. Such an investment will not be made without a reasonable assurance that the returns will be large. In other words, on the basis of a two million dollar investment, if one million is paid from bonds and one million from stock, under present conditions it would be practically impossible to secure investors in the original stock of the company, unless at least 15 percent can reasonably be anticipated on the entire investment, in which case the larger earnings would be secured by the owners of stock, who have risked their money practically without security. To effect this result, it would be necessary to issue stock to the amount of two million dollars and sell it on a paid-up basis of fifty cents on the dollar. The stockholder would anticipate an ultimate increase in the value of his holdings and a large return commensurate with his extra risks. A large return under such conditions must be possible, for the stockholder's property is the guarantee of the bonds which must be protected first, both in interest and principal. Here again, the total earnings of the plant, if successful, would show 15 percent on the investment. Unless actual prospects of such earnings are considered as fairly assured, a development along these lines is impossible.

In the first instance cited, the purchaser of the primary securities purchases what he believes to be a fairly safe investment, with the incentive of a certain amount of bonus stock which he hopes and believes will net him an additional return rather larger than he can secure from any other line of investment; and when such bonds are purchased from reliable investment houses who have made a specialty of certain lines of investment, and hence, have had long and valuable experience in a given line, the purchaser of such securities may receive some additional value besides his investment in the bonds of the company.

It is almost impossible at the present time, except under unusually favorable conditions, to build a two million dollar water power plant, or to develop almost any similar industry, by the issue of one million dollars in bonds and one million dollars in stock, to be sold at their par value. There are few investors who can come into close contact with the management of such properties as to make them feel assured that they will ultimately secure a suitable return on their stock; and investors who have not the knowledge or opportunity to assure themselves of the probable prospects of the investment, must depend upon the reputation of the investment house, the projectors of the scheme, or the engineer on whose judgment such securities are purchased; and such investors are not satisfied to take uncertain risks without prospects of large returns.

Fifteen percent on the total investment in a water power project is not more than a sufficient return when the risks in development maintenance and market are considered, and if the stockholders furnish an equity to the holders of bonds issued for only a portion of the cost, such stockholders who have taken the additional risk should be able to secure all of such returns on the total investment as are not required for the payment of bond interests.

Any of the above mentioned methods for financing water power industries by the issue of speculative stock, at less than par, and which, when honestly carried out are morally unobjectionable, are entirely impossible under the present restrictions in most states for any water power company that must operate as a public utility. Under the state laws, bonds can often be sold at a price as low as 75 percent, but stock in a public

utility—the owners of which must take practically all the risk in any speculative project—must be sold at par.

The ideas of the public, and especially of legislators and public officials, must change materially if the undeveloped water powers of the country are to be developed rapidly. The public interest should be conserved, but private interests must also be protected. As a rule, the very success of a project answers the question as to whether or not it is for the public good; for it appears that a man, who makes two blades of grass grow where one grew before, has performed an act no less beneficial to the public, the state and the nation if he reaps and harvests his grass and sells it at a profit to himself. No man will take part in water power development without the hope of an adequate reward, and when the hope of such a reward is removed, development will naturally cease.

The 70 800 Kv-a Transformer Bank

Of the Colfax Generating Station of the Duquesne Light Company

M. E. SKINNER
Transformer Engineer,
Westinghouse Electrical & Mfg. Company

THE main power transformers for stepping up the voltage from that of the generators at Colfax to that of the line have a rated capacity greater than any single-phase, two-winding transformers heretofore constructed. The rating of each transformer is 23 600 kv-a, giving a bank capacity of 70 800 kv-a corresponding to the generator rating of 60 000 kw at 85 percent power-factor. The initial installation consists of one 60 000 kw, three unit turbogenerator and four main transformers. The extra transformer will serve as a spare for both the first and the second bank which is to follow. In spite of the large capacity of these units, their physical dimensions are not greatly in excess of some transformers built previously of much lower rating and for service on lines of the same voltage.

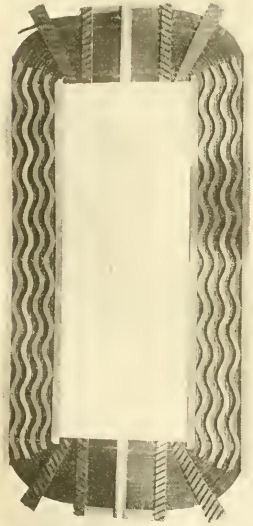

FIG. 1—HIGH VOLTAGE TRANSFORMER COIL

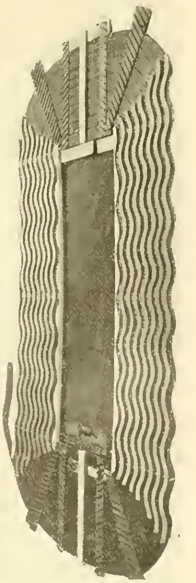

FIG. 2—LOW VOLTAGE TRANSFORMER COIL

Power is generated at 11 500 volts, three-phase, 60 cycles and is stepped up through the transformers to 66 000 volts at the present time and later will be raised to 132 000 volts. The generator voltage will be varied from as low as 11 000 to as high as 12 000 volts and the transformers are designed to deliver full rating at any voltage between these limits. No taps are provided on the low-voltage side, so that the high voltage developed will vary directly with the generator voltage. The bank is connected delta on the low-voltage side and star on the high voltage, so that the actual voltage ratio of each transformer is 11 500 to 38 100/76 200 volts. Full capacity taps are provided in the high-voltage winding for dropping the voltage a total of approximately 10 percent in four equal steps on the series connection and ten percent in two equal steps on the paral-

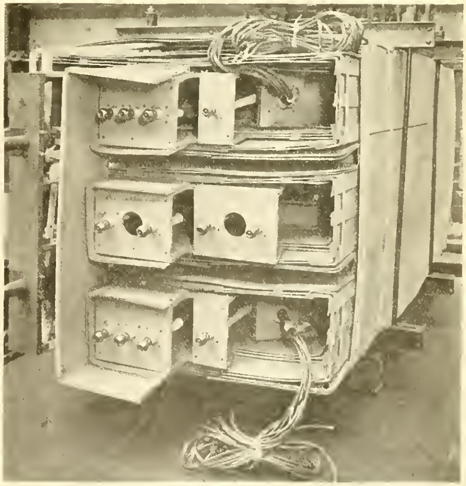

FIG. 3—ASSEMBLED COILS AND INSULATION IN POSITION

lel connection. The transformers are of the shell form of construction and are oil insulated water-cooled.

The winding consists of a number of rectangular pancake coils. Fig. 1 shows one of the high-voltage coils with the ventilating strips in place and Fig. 2 one of the low-voltage coils. The high-voltage conductor

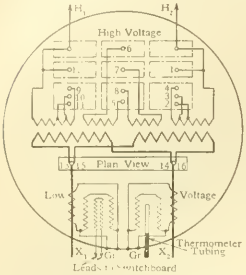

FIG. 4—DIAGRAM FOR CONNECTIONS OF THE HIGH-VOLTAGE WINDING

The connections are given in Table 1.

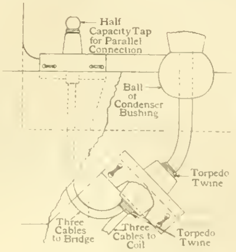

FIG 5—MOUNTING OF HIGH-VOLTAGE TERMINALS

is made up of three bare copper straps in parallel. The three straps are taped with several layers of treated cloth tape, to insulate the individual turns. The insulation between turns is reinforced toward the ends of the winding by spacing the insulated conductors apart by means of fullerboard strips run into the coil while it is being wound. The tapering of the insulation is quite clearly shown in Fig. 1.

In order to facilitate winding, the low-voltage circuit was divided into two paralleled sections. Each coil is wound of a number of double-cotton covered wires in parallel. The turns are spaced apart by means of fullerboard strips, as in the high-voltage coils. The low-voltage coils are among the largest ever manufactured, being almost nine feet in length. The high and

TABLE—I—SINGLE-PHASE AND THREE-PHASE STAR OR DELTA HIGH VOLTAGE—DELTA LOW VOLTAGE CONNECTIONS

Winding	Volts		Amperes	Connect
	Star	Delta		
High Voltage	132 000	76 210	310	6 to 7, 4 to 5, 3 to 2
	128 700	74 305	218	6 to 7 3 to 5, 8 to 9
	125 100	72 400	226	6 to 7, 3 to 5, 8 to 10
	122 100	70 495	335	6 to 7, 2 to 5, 8 to 10
	118 800	68 590	344	6 to 7, 2 to 5, 8 to 11
	66 000	38 105	620	1 to 7, 6 to 12, 4 to 5, 8 to 9
	62 700	36 200	652	1 to 7, 6 to 12, 3 to 5 8 to 10
	59 400	34 295	688	1 to 7, 6 to 12, 2 to 5, 8 to 11
Low Voltage		11 500	2 050	

low-voltage coils are assembled into groups. The insulation between coils within the group consists of channels over the straight sides of the coils, and washers of the same general shape as the coils themselves. Ventilating ducts are located on at least one side of every coil. They are obtained by spacing the washer from the coil by means of fullerboard strips. The wavy shape of these strips, as shown in Figs. 1 and 2, serves the double purpose of supporting every conductor at frequent intervals and of causing the cooling oil to pass back and forth over the surface of the coil, so that every conductor is cooled. The spacing strips are held in place by attaching them to the washers at their extremities and by fastening them to micarta cleats at frequent intervals so as to maintain a uniform spacing.

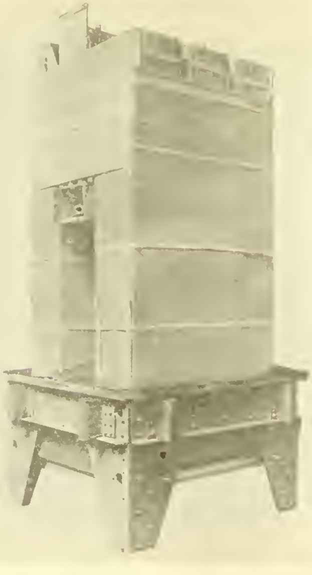

FIG. 6—ASSEMBLED COILS AND INSULATION IN PLACE READY FOR THE BUILDING OF THE CORE

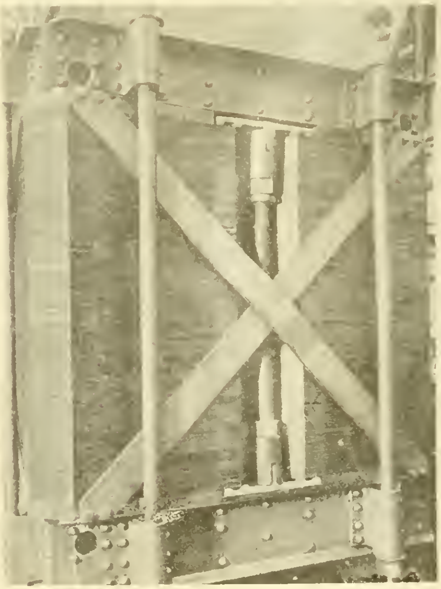

FIG. 7—DETAIL VIEW OF DIAGONAL CROSS BRACING

At the corners of the coils, special ventilated micarta spacers are used to support the turns more thoroughly at this point and to help direct the flow of the oil.

Each group of coils is then boxed in by means of fullerboard angles and washers and is banded together with stout webbing. The assembly of the coils and insulation is completed by stacking the groups one on top of the other, alternating high-voltage with low-voltage to obtain the proper interlacing. The boxing on each group serves to insulate each winding from the other winding and from the core which is to be built into this opening in the center of the coils.

The completed assembly of the coils and insulation is shown in Fig. 3. As will be noticed, certain of the washers are extended to form supports for the terminals. These extensions or bridges, as they are called, allow the complete assembly of the terminals before the building of the core is commenced, and provide a solid support for the terminals which is entirely free from rounded parts. In order to avoid the need

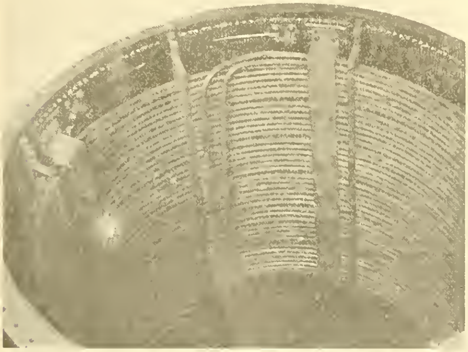

FIG. 8—GUARDS PROTECTING COOLING COILS

To minimize the danger of damaging the coils while the transformer is being tanked or untanked

of inspecting the high-voltage line lead connections, which of necessity must be located so far below the surface of the oil as to be rather difficult of access, the high-voltage lead is made continuous from the coil to the outer end of the high-voltage bushing. This explains the coil of cable in each of the outer high-voltage groups. In this particular instance, this construction was complicated by the series-parallel connection on the high-voltage winding. This was taken care of by using a number of cables in parallel for the line leads. One-half the total number of cables used are sweated directly to the coil lead while the other half are connected to the outer of four terminals immediately above the line lead as shown in Fig. 5. When the windings are connected in series, only one-half the cables in each lead is carrying current, but when in parallel they are all active. A diagram of the connections is shown in Fig. 4.

Fig. 6 shows the assembled coils and insulation in position in the lower frame ready for the building of the core. The punchings themselves are from high grade silicon steel specially treated to improve its magnetic characteristics. Owing to the high voltage de-

FIG. 9—HIGH-VOLTAGE FLEXIBLE CONNECTOR

veloped per inch of punchings, the laminations were given a special treatment in addition to the regular enameling, in order to keep the eddy current losses to a minimum. In fact, all through the design of these transformers, special features have been introduced with the idea of carrying the efficiency and reliability to the highest limits attainable commercially. The heavy structural steel frames which carry the weight of the transformers and clamp the core offer a magnetic path which parallels the core punchings almost all the way around the circuit. In order to keep stray flux and the resulting stray losses out of these frames, the core punchings are separated from the frames by wooden blocks. For the same reason the T-beams which pass through the coils at the top and bottom of the core are made of phosphor-bronze instead of structural steel.

As might be expected in a unit which handles so much energy in such a limited space, heavy mechanical stresses are unavoidable. The rugged and massive appearance of the transformer is mute evidence of the way in which these destructive forces are checked at every point.

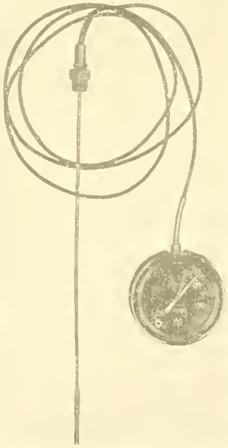

FIG. 10—LONG DISTANCE DIAL-TYPE THERMOMETER

For mounting on the side of the transformer compartment. The bulb is inserted directly in one of the heating coils on the low-voltage terminal board.

The forces in a transformer are primarily due to short-circuits. The heavy currents drawn at such times cause severe stresses of repulsion between the primary and secondary windings. In a shell-type transformer, the only portion of the coils which is not braced by the core is the extension of the coils at top and bottom. In these transformers, the ends are braced by placing two thick boiler plates against the insulation adjacent to

them and tying the plates together with heavy steel tie rods. The stresses of repulsion between primary and secondary act along the lines joining the electrical

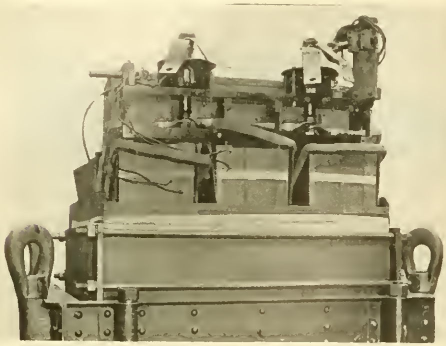

FIG. 11—CURRENT TRANSFORMERS AND HEATING COILS MOUNTED ON THE LOW VOLTAGE TERMINAL BOARD.

centers of adjacent groups of primary and secondary coils. If all the electrical centers lie along a horizontal line, the stress will be entirely repulsion between the various groups. If, however, due to manufacturing limitations, the electrical centers do not line up, there will exist a vertical component of force tending to slide the primary coils past the secondary coils. The phosphor bronze T-beams placed in the ends of the coil opening are spread apart by means of the large spreader bolts in order to brace against this vertical stress. They serve a further purpose in that the weight of the coils and insulation is transmitted through the spreader bolts to the lower end frame, completely eliminating any possibility of sag in the punchings.

Apparatus often receives very severe abuse in shipment. The stresses incident to being shunted around while in transit may be of considerable magnitude and are often of an entirely different character than those the machine is to be called upon to resist in its operation. In order to guard against possible distortion due to forces of this kind, these transformers are provided with heavy diagonal cross braces between the upper and lower end frames. Fig. 7 shows a detail view of the bracing.

The mechanical design of such a large transformer presents many items of interest. The heavy boiler plate tank is welded and is provided with a heavy angle rim to stiffen it. Four hooks are provided near the top for handling the complete unit. The cover is of flat boiler plate. A structural steel base is arranged to stiffen and reinforce the bottom and to transmit the stresses to the tank walls when the transformer is lifted. The base is provided with roller bearing wheels for rolling the transformer on a track. The cooling coils are constructed of seamless copper tubing. All joints in the tubing are brazed. The cooling coil is permanently mounted inside the tank, as the opening inside the cooling coil is large enough to pass the transformer without disturbing the coil. The cooling system is arranged to drain by gravity in case the water supply is shut off. Guards are placed over the cooling coil at the points where the transformer comes nearest to it, as shown in Fig. 8, in order to minimize the danger of damaging the coils while the transformer is being tanked or untanked.

To carry the heavy low-voltage leads through the cover, it was necessary to use four bushings, two leads being connected in parallel outside of the transformer. Although the transformers are to be located indoors at the present time, they are constructed for outdoor service. The high-voltage bushings are of the condenser type and are suitable for ultimate operation at 132 000 volts.

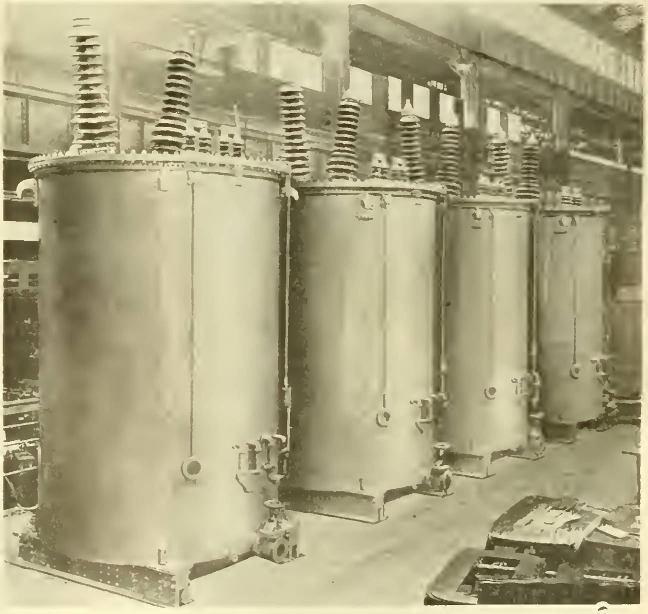

FIG. 12—23 000 KV-A SINGLE-PHASE TRANSFORMERS

The height to tip of high-voltage bushing is 23 ft. Over 5200 gallons of oil are required to fill the tank. The complete transformer, filled with oil, weighs 63 tons.

Wherever heavy leads attach to a bushing, it should be relieved of the strains incident to carrying the weight, and incident to the expansion and contraction

of the lead. This relief is provided by means of brush copper connections between the transformer terminals and the station wiring. The high-voltage connector, which is adapted for 1.5 in. copper tubing is shown in Fig. 9.

The great size of these transformers and the important position they occupy in the transmission system warrants special precautions for protecting them and operating them intelligently. By means of temperature indicating devices, the hottest spot temperature of the windings will be shown continuously, both on the main switchboard and on the outer wall of the transformer compartment. Both indicators operate on the same principle. A current transformer over one of the low-voltage leads supplies a small heating coil with a current always proportional to the load current flowing in the main transformer windings. The heating coil is designed to generate and dissipate heat at the same rate as the main windings. Its temperature is always greater than that of the hottest oil in which it is immersed by the same amount as the main winding temperature is greater than that of the oil adjacent to it. The temperature within the heating coil, therefore, is always the same as that of the hottest portion of the main winding. The switchboard mounted indicator measures the temperature within the small coil by measuring the change in the resistance of a resistance element embedded within the coil. A Wheatstone bridge method is used, the voltmeter reading the unbalance of the bridge being calibrated in degrees C. Energy is supplied to the bridge from a 125 volt direct-current circuit. The indicator, which is mounted on the side of the transformer compartment, consists of a long distance dial-type thermometer, whose bulb is inserted directly in one of the heating coils. This type of thermometer is shown in Fig. 10. Fig. 11 shows the details of the current transformers and the heating coils mounted on the low-voltage terminal board.

With an accurate indication of the hottest temperature of the windings of the transformer available at all times, the rating of the transformer becomes nominal. The load may be controlled to keep the transformer operating at its maximum safe operating temperature when the temperature of the cooling water decreases, so as to utilize fully the increase in capacity made available in this way. If water is expensive and it is not convenient to adjust the load, the amount of cooling water may be considerably decreased when the load is light. In either scheme of operation the temperature indicator is the guide. The indicator mounted on the outside of the transformer compartment is provided with alarm contacts so that a bell or lamp alarm may be operated in case anything goes wrong.

In spite of the relatively small size of the transformers in comparison with the amount of power handled, they are among the most efficient ever built. At all loads between one-half and full load the efficiency is over 99 percent and at full load it is slightly under 99.1 percent.

Heat Balance Systems

F. C. CHAMBERS
President
Des Moines City Ry. Co.

and

J. M. DRABELLE
Mech. and Elec. Eng.
Iowa Railway & Light Co.

THE problem of maintaining constant temperature boiler feed water, regardless of load and irregular rates of feeding, is of the greatest economic importance in the operation of a power plant. If boiler feed water can be maintained at approximately 212 degrees, before going to the boiler or economizer, the maximum steaming capacity of the boiler plant can be realized. High feed water temperature also reduces the amount of disolved air in the feed water, which has a marked effect upon the corrosion of drums, headers and tubes in the boiler. Furthermore, the reduction in the amount of disolved air and non-condensable gases contained in the water reduces the duty on the condenser air pump, thereby giving a better vacuum.

Several methods of maintaining constant feed water temperatures have been proposed, but most of them are mere approximations. They secure the desired result only at certain points on the load curve.

METHODS OF AUXILIARY DRIVE

Steam Driven Auxiliaries—Steam driven auxiliaries have been used in some stations entirely, exhausting into the feed water heaters. These are open to the objection that they deliver practically a constant quantity of steam to the heater, without regard to the load on the prime movers. Consequently, if sufficient steam is supplied for the maximum load condition of the station, large quantities of steam are wasted at light loads. Furthermore, the amount of steam required in the heater varies, due to irregularities in feeding water into the boiler. In other words, the station with entirely steam driven auxiliaries would have its heat balance at but one point.

Mixed Steam and Electrically-Driven Auxiliaries—This is an attempt to balance conditions approximately at all times. It depends on close observation by the operating force as to the temperature of the feed water and a constant changing from steam to electric drive in order to avoid either a waste of steam from the relief valve of the heater, or low temperatures of boiler feed water. This method is objectionable because, with a rapidly fluctuating load such as is encountered in railway operation, it would be impossible for the operators to change from electric to steam fast enough to follow the load fluctuations and the irregularities of boiler feeding.

Flow Valves—Bleeding steam from the main turbine generating unit by means of a flow valve has also been tried out. However, this introduces a complication in the operation of the main turbine units. There is always a dispute in regard to the water rate of the unit. There is danger of the flow valve sticking and

FIG. 1—HORIZONTAL REGULATOR WITH SPRING AND BELL CRANK MECHANISM
Mounted on house turbine

steam being taken at light loads from the heater back into the turbine, thus causing overspeed.

Combinations—Some plants make use of all steam driven auxiliaries and then depend on a by pass valve, or some form of flow valve to by-pass such amount of steam as is not required in the feed water heater, back into the main turbine unit at one of its low pressure stages. This results in a rather complicated piping system, introducing a considerable quantity of air which puts additional burdens on the air pump and condenser. This system also requires hand operation, with resultant objections.

The House or Auxiliary Turbine—A house or auxiliary turbine is used in generating stations in which all of the auxiliaries, except the boiler feed pump, are electrically driven. In one system a condensing turbine is used, exhausting into a barometric condenser through which the condensate from the main generating unit passes. The heat from the exhaust steam of the turbine is absorbed by the condensate. This system does not answer the requirements of maintaining a constant feed water temperature at all times, unless some method is provided to vary the load on the auxiliary turbine. The amount of load taken by the auxiliary turbine will vary according to the quantity of water to be heated, both condensate and make-up. Some auxiliary device, therefore, is necessary to vary the load on the turbine. An added complication of this scheme is the piping, which must be so arranged as to allow the supply of make-up water to be delivered into the condensate line between the condensate pump of the main turbine unit and the barometric condenser.

The other system of auxiliary turbine proposed and placed in actual operating service, is the non-condensing turbine, exhausting into an open feed water heater. In this system all of the auxiliaries, excepting the boiler feed pump, are electrically driven. The auxiliary turbine is electrically connected to the main generating bus of the station through a bank of step-up transformers. In order to take care of the variation of steam demands on the auxiliary turbine, the load on this turbine is varied by means of an automatic controller.

To the piston of this automatic controller is connected one end of a flat spring, the other end being attached to the bell crank operating the admission valve to the turbine, as shown in Fig. 1. The piston is actuated by water pressure supplied from the house system. The pressure for actuating the diaphragm of the controller is taken from the main auxiliary exhaust header at a point about 20 feet from the turbine, so that this pressure remains practically constant under balanced conditions and is not influenced by a sudden change in load of the auxiliary turbine.

To illustrate the operation of this controller, assume the following conditions: Load on main generating units 4000 kw; water being supplied to heaters by condensate pumps at the rate of 80 000 pounds per hour; load on auxiliary turbine to supply the necessary steam to raise the temperature of the feed water from 50 to 215 degrees, 150 kw; pressure on auxiliary header, one pound gage. Now assume that, due to a sudden change of load to 6000 kw on the main units, such as constantly occurs in central stations supplying either an exclusive railway load, or a combination lighting and railway load, the amount of condensate to the feed water heaters is increased from 80 000 to 110 000 pounds per hour. In order to maintain the temperature of the feed water constant, or nearly so, it will be necessary to increase the quantity of exhaust steam from the auxiliary turbine in approximately the same ratio or about 40 percent.

The auxiliaries of the station will require practically no additional power under the increased load conditions. It is evident that, if sufficient steam is to be furnished from the auxiliary turbine to heat the increased amount of condensate to a maximum temperature, the load on the auxiliary turbine must be corre-

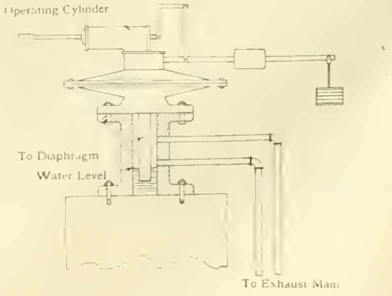

FIG. 2—MASON HORIZONTAL TYPE HOUSE TURBINE CONTROLLER

spondingly increased. This is accomplished in the following manner:—

When the quantity of condensate is increased from 80 000 to 110 000 pounds per hour, the result is a slight reduction in pressure on the auxiliary header. This is

because the auxiliary turbine is not supplying sufficient steam to maintain one pound pressure on the diaphragm of the controller, which will therefore move. This movement operates the pilot valve, admitting water to the cylinder of the controller. The tension on the auxiliary spring between the controller and the bell crank actuating the admission valve to the turbine is increased, increasing the steam flow into the turbine. The additional load is built up through the bank of step-up transformers between the auxiliary bus and the main bus. Under these conditions, that is with a load of 6000 kw, the auxiliary turbine is now delivering 150 kw to the auxiliaries and approximately 75 kw to the main bus. This condition of balance both in electrical load and steam supply for heating the feed water remains constant until another change takes place in the load.

PROTECTIVE FEATURES

Because the house generator runs in parallel with the main station bus, it is imperative that adequate pro-

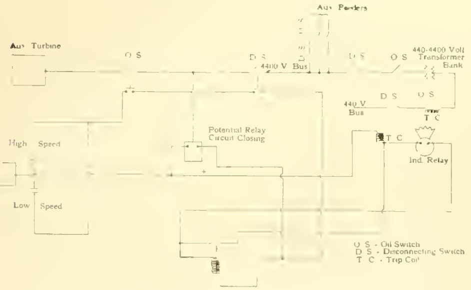

FIG. 3—SCHEMATIC DIAGRAM OF AUTOMATIC PROTECTION FOR AUXILIARY TURBINE

tective devices be provided so that in case of any abnormal disturbances, the auxiliary turbine may be promptly cut off from the main generating bus, thereby permitting a continuous and uninterrupted operation of the auxiliaries. This is accomplished as follows:—

1—In case of rise in frequency on the main generating bus, it is essential that the auxiliary turbine trip out the bus tie switch before the over-speed device on the auxiliary turbine may operate. This form of protection is secured by an overspeed switch on the shaft of the auxiliary turbine opening the main tie-switch between the transformers and main generating bus.

2—To prevent trouble from a reduction in the main generating bus frequency, due to either overload or high-tension disturbances on main bus, an under-speed switch is also incorporated. This device is mounted on the end of the turbine shaft so that in case of a frequency lower than normal, the bus tie switch will operate. Were it not installed, the lowering of frequency and consequent drop in voltage would cause the auxiliaries of the station to drop out, as these are all electrically operated and equipped with contactor control.

If the station bus voltage is maintained by a Tirrill regulator, the frequency could become very low before the contacts of the control equipment would open. A further object of the underspeed switch is to prevent the slowing down of the auxiliaries, including the motor driven exciter, in case of a reduction in the frequency of the main bus. This also prevents the lowering of the frequency of the auxiliary turbine, preventing the dropping out of the contactors under this condition. The idea of the under-speed device is to keep the auxiliaries, including the motor driven exciter, up to speed at all times and to enable the auxiliaries to be kept at a normal speed, in case of low steam pressure when it is desirable to hang on to the load.

TABLE I—MONTHLY STATION PERFORMANCE FOR FEBRUARY, 1921

Feed Water temperature leaving heater	214° F
Feed Water temperature going to heater	54° F
Feed Water weight	45 928 000 lbs
Total Kw-hr. main units	2 063 220
Kw-hr. generated by auxiliary turbine	124 300
Kw-hr. delivered to main bus	25 100
Kw-hr. taken from main bus	
Kw-hr. total to auxiliaries	99 200
Evaporation per lb. fuel	6.08
B.t.u. per lb. of coal as fired	8645
Fuel per Kw hr.—total station	3.62

3—Low voltage on the main generating bus is taken care of by potential relays. These will close their contacts in case of low potential, thereby energizing the trip coil of the bus tie switch, cutting the auxiliary turbine free from the main generating bus. If this condition was not taken care of the auxiliaries would drop out.

4—Should the auxiliary turbine be shut down for repairs or overhauling, power for the auxiliaries is taken from the main generating bus. In this case interlocks are provided on the disconnecting switches and oil switches to prevent the operation of the main bus tie switch. Interlocks are also provided on the disconnecting switches to permit the station operator to test out the oil switch with the disconnecting switch open, before synchronizing the auxiliary turbine with the bus.

5—High current protection is taken care of by induction type relays set for approximately 300 percent normal current and five seconds delay. These relays are practically inoperative, except in case of short-circuits on the auxiliary bus.

TABLE II—ANALYSIS OF A CENTRAL STATION SUPPLYING A RAILWAY AND LIGHTING LOAD AND A CENTRAL STEAM HEATING SYSTEM

1—Water evaporated in twelve months	1 070 530 558 lbs
2—Average temperature feed water	180° F.
3—Average temperature initial	60° F
4—Rise in heater	115° F.
5—Total steam in pounds to auxiliaries	111 500 000
6—B.t.u. per pound of steam at zero gauge	970
7—Water rate auxiliary turbine	35 lbs pr. Kw-hr.
8—Size of auxiliary turbine	1200 k.w.
9—Water rate per B.Hp-hr. at motor shaft	30.2 lbs.
10—Total lbs. steam motor driven auxiliaries, through auxiliary turbine	61 000 000
11—Saving per year in lbs steam over present mixed drive (5)—(10)	50 500 000
12—Evaporation per lb. of coal (8500 B.t.u.)	6
13—(11) divided by (12) 8 400 000 lbs *	4200 tons
14—Tons of coal saved per year due to increasing average temperature of feed water from 175 to 215 degrees	1417
15—Average cost per ton 1920	$6.25
16—Total cost (13) and (14)	$35 721.25
17—Saving in dollars per year in coal	35 106.25
18—Estimated saving per year in maintenance of electrically driven auxiliaries over steam	6 900.00
19—Total annual saving	$42 006.25

An interesting application of this form of house turbine has already been made at the plant of the Des

*Increasing feed water temperature to 215 degrees F. will give 945 000 kw.-hr. from the auxiliary turbine, also for each 10 degrees rise in feed water temperature one percent saving of fuel or four dollars.

Moines City Railway Company at Des Moines, Iowa and has been in very successful operation for a period of years. The regulator acts through a lever mechanism on the auxiliary spring of the turbine governor. In order to secure successful operation of the hydraulic control, considerable care had to be taken in the piping to and from the exhaust main. The upper pipe, shown in Fig. 2, merely serves to conduct pressure from the exhaust header to a reservoir and the condensation which takes place in the reservoir is carried back into the exhaust header by the lower, or drain pipe. It was found from actual experience that it was impossible to secure satisfactory operation with only a single pipe leading to the diaphragm of the regulator without the use of the reservoir.

The economics of the auxiliary turbine are extremely interesting as shown in Table I.

The charts from the recording instruments of the Des Mines City Railway station shown in Figs. 4 and 5 illustrate the actual operation of this system. These two charts clearly show that the application of the auxiliary turbine, with control devices as mentioned, is not only correct in theory, but in actual practice. It will do exactly what it was designed to do, and in addition to maintaining a constant feed water temperature, regardless of the load, it has carried the auxiliaries of the station and has delivered some power to the main bus.

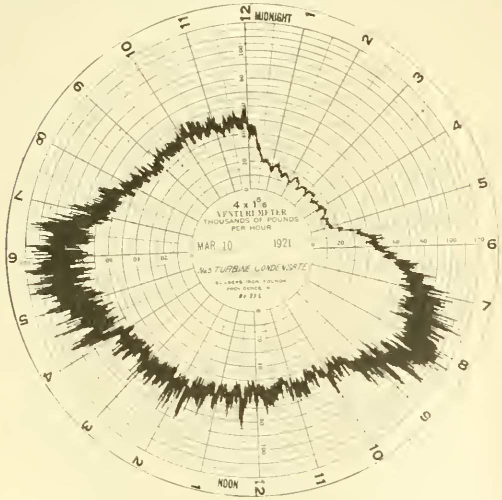

FIG. 4—VOLUME RECORD OF CONDENSATE

Another application of the house, or auxiliary turbine, has been proposed for a large central station, which not only supplies a railway and lighting load, but also is burdened with a large heating system. In this case not only the water for boiler purposes, but in addition a large amount of makeup water must be heated on account of the enormous quantity of steam sent out through the heating mains, which requires that make-up water be taken from an outside source and heated to 212 degrees. An analysis of the saving expected from the auxiliary turbine is given in Table II.

The advantages and disadvantages of the auxiliary turbine may be summed up as follows:—

ADVANTAGES OF AUXILIARY TURBINE DRIVE

1—Maximum feed water temperature during peak loads when greatest boiler capacity is needed, thereby permitting use of less boiler capacity on peak load.

2—Considerable reduction in auxiliary piping which is required when each auxiliary is steam driven requiring both steam and exhaust piping, also oil piping.

3—Reduction in condensation losses due to eliminating auxiliary exhaust and steam piping, the losses of which go on for 8700 hrs. per year as it is not practicable to shut off valves on main auxiliary header each time a main unit is shut down.

4—Greater reliability secured in using induction motors of very rugged design as compared to small, inefficient, high speed turbines, necessitating gearing in some cases to secure best speed for pumps.

5—Lower steam consumption for auxiliaries account of higher efficiency of motors and large auxiliary turbine.

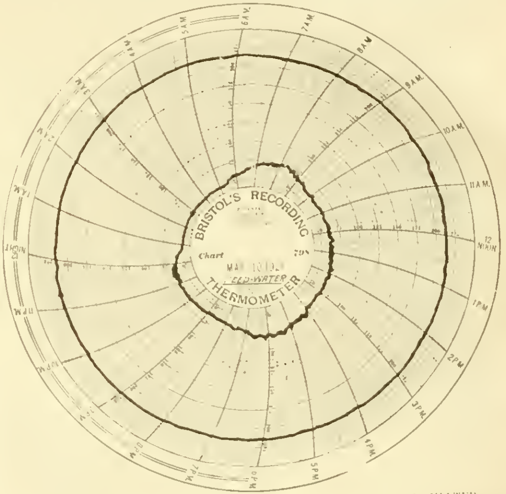

FIG. 5—TEMPERATURES OF CONDENSATE AND FEED WATER

6—Lower maintenance cost on large auxiliary turbine and motors driving auxiliaries, as compared to many small turbines or engines.

7—All water, condensate or raw, contains a certain amount of air and unless some means is provided for eliminating air before water is fed into boilers, a considerable amount is carried in with feed water, resulting in pitting and corrosion, and with steel economizers, corroding them. Air is driven off and a lesser quantity of air is carried over with steam and reduction of amount of air handled by air pump.

DISADVANTAGES

1—Initial cost is somewhat higher than that of steam or combination driven auxiliaries.

2—Factor of safety in a station of four main generating units each equipped with steam driven auxiliaries, is higher than in the same station equipped with one auxiliary turbine.

BIBLIOGRAPHY

N. E. L. A. Prime Movers Committee 1920 Report Engineering of Power Plants, Fernald and Orrock Bau Grosser Elektrizitatis Werke, Klingenberg.

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Electrical Propulsion for Battleships

The completion of the preliminary trials of the U. S. S. *Tennessee* marks an epoch in naval history. While not the first capital ship to be electrically driven, it is the first one, designed especially for electric propulsion, in which the full advantage of this system has been utilized. The success of the U. S. S. *New Mexico* was sufficient demonstration of the possibilities of electric drive. From a military standpoint, however, she was not much in advance of her sister ships, as she was originally designed for direct turbine drive and the electric propelling machinery was fitted into the space available with as little change as possible.

At the time it was decided to install electric propelling machinery in capital ships, it was realized that a more advantageous disposition of the machinery could be made, but as the designs of the U. S. S. *New Mexico* were so far advanced, it was decided not to make any radical changes. When the designs of the U. S. S. *Tennessee* were made, however, full advantage was taken of the possibilities which the electrical system offered, to obtain a layout giving the maximum protection to the machinery which this system allows. The experience that had been gained from the war, up to that time, showed the vital necessity of adequate underwater protection if the ships were to be capable of remaining in action during a modern battle where torpedoes are used so freely. The freedom with which the naval designer can dispose of his machinery with the electrical system, makes possible bulkhead subdivisions not feasible with any other type of propelling machinery, the location of which is necessarily governed by the position of the propeller shafts, so that the U. S. S. *Tennessee* is probably the best protected capital ship afloat today.

As has been the history of electrical development in many branches of industry, the real advantages have not always been obvious or fully appreciated. Generally in such a new development, stress is laid upon such factors as economy and it usually does not develop, until a very careful study and detail design has been made, that there are other advantages of even greater importance. In the design of battle ships, any tool that will enable a better fighting machine to be built, can be used to advantage if it does not have other characteristics which would distract from the operation of the machine as a whole. While in the first place, stress was laid upon the economy of electric drive and while the claims of the advocates of electric drives have been justified by the operation of the U. S. S. *New Mexico*, it is believed that the greatest advantage of the electric system is the fact that it enables the naval constructor to build a better fighting machine for modern warfare.

The idea in using electrical machinery for propelling ships, is not of recent origin. As far back as thirty years ago, the idea was suggested to the Navy Department to drive ships then contemplated with electrical machinery along almost the same lines as were eventually adopted. If the suggestion had been carried out at that time, it would probably have been a failure, as the development of suitable prime movers and electrical machinery had not progressed far enough to enable results to be obtained comparable with what was then possible with the existing systems. During this period, however, the steam turbine and the electric generator have been highly developed for central station use in capacities much greater than required for our modern ships so that, except in so far as slight modifications were required for fitting the machinery into a ship, no new problems were involved. This was also the case with the motors used for driving the propellers. Larger machines have been developed and in use for a number of years under severe operating conditions in our steel mills, so that the problem was reduced to the comparatively simple one of a study of the conditions under which a machine had to operate and then of designing it with the proper characteristics. While in the main, this was a simple problem, it involved an immense amount of detail study as is evidenced by the descriptions of the various parts of the equipment given in this issue of the Journal.

With the adoption of electric propelling machinery, the American naval constructor has been enabled to design a capital ship with such protection that it is difficult to conceive of such a ship being seriously inconvenienced by under water attack. The progress in the development of armor protection has been such that a modern ship can stand an immense amount of battering without being put out of action, as was instanced by the "*Warspite*" in the battle of Jutland where, owing to a defect of the steering gear, she was compelled to circle around for a considerable period and received at one time or another, the fire of practically the whole German fleet but still remained an active fighting machine. The experiences of war forced the British to adopt some means of protection against torpedo attack with the result that they fitted a great many of their ships with the so-called "bulge" which was partially effective. In the design of the U. S. S. *Tennessee*, however, it has been

possible to incorporate the desired protection much more effectively in the hull of the ship, due to the freedom with which the machinery could be disposed, so that a commander of a fleet of such vessels could go into action with the feeling that he was practically immune from torpedo attack and could maneuver accordingly instead of being restrained, as were the British during the battle of Jutland, by the repeated efforts of the enemy to seriously cripple the principal fighting units by using large numbers of torpedoes.

WILFRED SYKES

The Battleship is a Fighting Ship

In considering any new engineering development or undertaking, it is of the greatest importance to get clearly in mind the fundamental reasons for such development, and the fundamental results to be accomplished. It is equally important to keep these ideas in mind continually during the period of consideration and development.

Fundamentals are a guide to our mind; they keep us on the track and prevent secondary considerations from assuming undue proportions. Most engineering mistakes are due to lack of appreciation of the basic laws governing our own progress. Fundamentals protect us from the results of prejudice and limited experience; they enable us to go safely into the future and to decide new questions correctly in the light of our past experience.

For a number of years there has been a good deal of discussion about electrically-driven battleships. Looking back at these discussions, it is quite apparent that many of them were affected by prejudices and the pride of attainment. Many of the men taking part in the discussions did not keep in mind the fundamental fact that a battleship is a fighting ship. In considering the question of the battleship, nothing should govern but fighting qualities,—difficulties of accomplishment, cost, appearance, convenience, efficiency, cost of operation, are all of secondary consideration, and should be sacrificed willingly and completely, if by so doing the fighting quality is enhanced.

About a year ago the writer had occasion to discuss the subject of electrically-driven battleships with a number of English engineers who had had much to do with the designing of propelling machinery for battleships. The distinct impression was received that their minds were not open; that their decisions and judgments were vitiated by the results of their own past decisions. They had not clearly in mind that what had already been done was of no particular value; that the thing to keep constantly in mind was that "the battleship is a fighting ship." They were all favoring turbine gear drive. There is no question that the turbine gear drive was a great advance over the old reciprocating engine, judged by the greater fighting ability of the ship. There seemed, however, to be an unwillingness to consider the electric drive from the same standpoint.

Now, in what way does the propelling system of a battleship affect its fighting qualities? Briefly, they may be stated as follows:—

Reliability
Economy
Weight
Space occupied
Flexibility of arrangement
Flexibility of operation and maneuvering
Possibility of protection from shell or torpedo explosion
Quickness and ease of making repairs either on board or in dock
Possibility of a shutdown of the propelling machinery
The effect of the propelling machinery on the design of the ship itself.
The effect of the propelling machinery upon the arrangement and design of other apparatus.

Each of these has an effect upon the fighting quality of the ship, either directly or secondarily, through its effect upon other matters.

It is quite evident to an unprejudiced observer that the electrical propelling machinery, as installed in the new battleship *Tennessee,* excels in all of the above qualities, with the possible exception of those of weight and space, direct comparisons of which are not available. Also there is no direct comparison available in regard to the economy. However, analysis of this item shows that over the entire range of speed and power, the electric drive should be the most economical.

In having the open-mindedness which led to conviction, the courage to follow conviction, and the skill and engineering ability to carry out plans, our Navy Department and the contractors working under their supervision have produced a ship of which we can all be proud. More than that, they have won a battle, not of shells but of engineering. The time is near when electric propulsion will be recognized by all as not only successful, but as excelling, and that the *Tennessee* is the prototype of the future battleship.

Since the text for this issue was prepared, the *Tennessee* has completed her official trials. It will be a great satisfaction to everyone who has been connected with this important development to know that the propulsion system met all of its guarantees and showed gratifying results as regards steam consumption, which in every test were materially better than guarantees. Full details of the trials will be published later. These results are further proof of the wisdom and foresight of the Navy Department in selecting electric drive for their capital ships.

W. S. RUGG

Electric Drive and the U. S. S. Tennessee

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ONE of the very important advantages of a modern navy—and one that is being emphasized too little in the current naval discussion—is that it acts as an immense laboratory for experiments in marine engineering. Everyone will admit that America's merchant marine should be progressive and should adopt new and better forms of equipment as soon as they are thoroughly developed, but few realize the difficulties involved in transferring an application successful on land and adapting it for marine use. So great are these difficulties, so large is the expense, even in case of success, and so huge the loss in money and prestige in case of failure, that few private marine interests can afford to be the first to introduce important radical departures from ordinary procedure. Hence it is a fact that the Navy, which is always interested in new developments, has been the medium through which a large number of the modern improvements have been introduced into the merchant marine.

Undoubtedly the foremost example of the influence exercised by the Navy in American industry is our steel industry. In the early eighties of the last century, America's fleet of fighting vessels consisted of a few obsolete monitors. The need for a real Navy was apparent, however, and plans were prepared for a squadron of first class ships. But these ships could not be built without foreign aid because nowhere in America could the forgings needed for the armor-plate and the heavy guns be obtained. To the everlasting credit of the Navy, it refused to purchase this material abroad and made arrangements with American manufacturers to install the necessary equipment for the production of this armament. Thus the famous "White Squadron" greatly accelerated the development of the American steel industry, and though the ships never fired a shot against an avowed enemy of the United States, and were therefore in one sense a total loss to the nation, their cost was an insignificant price to pay for the wealth that they created.

Similarly (to mention only that class of apparatus which is most familiar to the writer) the Navy has been responsible for the development of all of the modern drives for ships. British destroyers were the first to use the direct-connected turbine; an American collier proved the practicability of the geared turbine, which is now one of the dominant types of ship propelling machinery; German submarines developed the marine Diesel engine, which is the most economical of all drives; and the American Navy has boldly departed from all precedent and created the steam-electric drive, which is undoubtedly ideal for all large, high-powered, variable-speed ships and which, in the modified form of the Diesel-electric drive, promises to share with the geared-turbine in the propulsion of the merchant marine.

FIG. 1—OFFICERS OF THE TENNESSEE WHEN COMMISSIONED AT THE BROOKLYN NAVY YARD*

Though many engineers undoubtedly conceived independently the idea of the electric drive for ships, the credit for its first adoption by the U. S. Navy belongs to Mr. W. L. R. Emmett, consulting engineer of the General Electric Company, actively supported by Captain R. S. Griffin, Captain C. W. Dyson, and Admiral H. I. Cone, all of the Bureau of Steam Engineering, U. S. Navy.

Although vessels had been electrically propelled as early as 1893, the first installation of importance was the collier *Jupiter*, commissioned in 1913. The *Jupiter* was one of three sister ships—one (*Jupiter*) electric-

ally propelled; another (*Neptune*) equipped with geared turbines; and the third (*Cyclops*), whose disappearance is one of the tragic mysteries of the war, with reciprocating engines. This was truly an experiment on a large scale and demonstrated the reliability of electric propulsion and its desirability for use in capital ships, and the excellence of the geared-turbine drive for all other classes.

The next step in the history of electric drive was its installation on a battleship in 1915. Three ships were authorized at that time, *New Mexico, Mississippi*, and *Idaho*, the first to be built at the New York Navy Yard, and the other two at private yards. The Navy Department requested the private builders to quote on electric drive but they refused to consider anything so unfamiliar, so the Navy decided to do the work itself, which is another instance of its initiative. Hence the *New Mexico* has the honor of being the first electric battleship. She was commissioned in 1918 and her subsequent performance has amply justified her designers and sponsors.

Authorization for electrically-operated capital ships followed rapidly after that, the present schedule being as follows:—

TENNESSEE CALIFORNIA	Practically sister ships of the NEW MEXICO.
MARYLAND COLORADO WEST VIRGINIA WASHINGTON	Similar to the TENNESSEE, except that they will carry eight 16-inch guns instead of twelve 14-inch guns.
INDIANA SOUTH DAKOTA MONTANA NORTH CAROLINA IOWA MASSACHUSETTS	These will be much larger than any battleships now afloat.
CONSTELLATION RANGER CONSTITUTION UNITED STATES LEXINGTON SARATOGA	Battle cruisers of immense power and speed.

*Figs. 2 and 4 by Clinedinst, Wash. D. C.
**Copyright by Clinedinst, Wash., D. C.

Of these, the *Tennessee* has successfully completed her final trials, and the *Maryland* and *California* will be ready for trials this year. The *Tennessee* is the latest of our battleships to join the fleet. Her hull design was supervised by Rear Admiral D. W. Taylor, Chief of the Bureau of Construction and Repair, and her ordnance by Rear Admiral J. Strauss, Chief of the Bureau of Ordnance. Her machinery was built under the supervision of Rear Admiral R. S. Griffin, Engineer-in-Chief, U. S. Navy, Rear Admiral C. W. Dyson and Commander S. M. Robinson being in direct charge of the details of its construction. On Commander Robinson's appointment as Engineer Officer of the Pacific Fleet, his work was continued by Commander J. S. Evans. She was built in the New York Navy Yard under Rear Admiral G. E. Burd, Industrial Manager of the Yard; Captain P. B. Dungan, Engineer Officer; and Captain G. H. Rock, Construction Officer. Her contract was signed in December 28, 1915; her keel was laid on May 14, 1917; she was launched on April 30, 1919; and she completed her trials on May 21, 1921.

FIG. 2—REAR ADMIRAL D. W. TAYLOR*

FIG. 3 REAR ADMIRAL ROBERT S. GRIFFIN**

FIG. 4—REAR ADMIRAL C. W. DYSON*

Her trials proved conclusively the superior maneuvering power due to her electric drive. A maximum speed of 21.378 knots was attained; she came to rest from top speed in less than three minutes; she was driven backward at over 15 knots; and her turning circle, with all propellers operating in one direction and with rudder hard-over, was less than 700 yards, or about that of a destroyer. Her economy trials were also eminently satisfactory, and her steam consumption guarantees were improved by from 5 to 10 percent. Her trials were conducted by a board composed of Rear Admiral G. W. Kline, President of the Board of Inspection and Survey, and Captains H. D. Tawresey, W. N. Jeffers, and P. B. Dungan, the latter being especially in charge of her engineering inspection.

One of the interesting features of the *Tennessee*

is her relation to her name-state. Through a new policy, of which she is the first example, she has been made practically an extension to the educational system of that State, since service on board of her provides an unparallelled course of training, travel and education, and native-born Tennesseans are given preference wherever possible. Prior to her being commissioned, Governor Roberts of the State of Tennessee, and Captain Leigh of the ship, toured the State in the interest of recruiting, and as a result over half of her crew are native sons.

FIG. 5—COMMANDER S. M. ROBINSON†

FIG. 6—COMMANDER J. S. EVANS†

FIG. 7—REAR ADMIRAL G. W. KLINE

FIG. 8—CAPT. RICHARD H. LEIGH*

Captain Richard H. Leigh, Commanding Officer of the *Tennessee*, has had an active and varied career. His earlier experiences include a deep-sea survey of the Carribean and North Pacific Seas, service on the *Princeton* during the Spanish-American War, and serving as assistant to the Bureau of Steam Engineering. Shortly after America entered the Great War, he attained the rank of captain, and was assigned to duty with Vice-Admiral Sims at London. He had charge of all the submarine chasers in foreign waters, and was especially concerned with the installation of submarine detecting devices. For his work in this latter field, he was awarded the order of the British Empire by King George and the Order of Leopold by King Albert. After the armistice he was appointed as

FIG. 9—COMMANDER CLAUDE A. JONES**

Assistant Chief of the Bureau of Navigation serving also for some months as Acting Chief. Later he was ordered to New York in connection with the fitting out

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**Photo by Ewing Galloway, New York.
†Figs. 5 and 6 copyright by Harria & Ewing, Wash., D. C.

of the *Tennessee,* assuming command of this vessel in May, 1920.

Commander Claude A. Jones, Engineer Officer of the *Tennessee,* has devoted himself to the study of marine engineering ever since his graduation from the Naval Academy in 1907, and has served as engineer officer on several vessels. In 1915, when he was on U. S. S. *Memphis* (the old *Tennessee*) in San Domingo Harbor, a tidal wave struck the ship, lifted her upwards, and then crashed her down upon the rocks. The shock, which wrecked the vessel, broke the main steam pipes and filled the interior with live steam. Jones made his way to the engine room and helped to rescue the crew. He was very badly burned and was confined to the hospital for many months. Upon his recovery, which at one time was not expected, he was assigned to the Westinghouse Company's plant at East Pittsburgh where he was inspector for the electrical apparatus for the *Tennessee.* On its completion, he was ordered to the New York Navy Yard to superintend the installation of this machinery, and was then transferred to the ship as Engineer Officer. The successful results of the trials of the ship bear witness to his efficiency in organization and operation.

Motion--$30 000 000 Worth

COMMANDER R. A. BACHMANN M. C., U. S. N.
U. S. S. Tennessee

FOR a year the Chief had worried. For a year he had poured his soul out over plans and blue prints, and struggled with yard workmen and heads of departments and the Bureau of Engineering and other important people, for the Chief had been ordered to the New York Navy Yard in connection with the building of the U. S. S. *Tennessee* and it was up to him to see that generators generated and the motors moted and the propellers propelled; in short, that the magnificient piece of electrical engineering which was designed to furnish this latest type of battleship with sufficient horse-power to drive her through the water at a speed of twenty-one knots, should be in proper shape to deliver the goods. So the Chief had worried and now the day had come—the beginning of the week of acceptance trials to be held over the official course off Rockland, Maine.

FIG. 1—THE TENNESSEE MAKING OVER 21 KNOTS PER HOUR ON HER TRIAL TRIPS OFF ROCKLAND, MAINE*

Once before the writer of this article had been on a speed trial. The ship was one of our fastest cruisers, but she burned coal and had reciprocating engines. The excitement had been intense. The engine room was filled with officers and enlisted men dripping with oil, their faces glistening, their clothes saturated. It was impossible to talk. The thump-thump of the engines and pumps, the hiss of escaping steam, the rumble of the shaft filled the air. Floor plates glistened with oil, water and oil dripped from frames and braces, in a minute you were soaked, Long, steel rods shot out from cylinders like giant arms and turned the crank shafts like an Italian turning his hurdy gurdy.

Forward of the engine room were the pumps doing their share of the work, adding to the confusing array of rods, wheels, cylinders, valves, bolts and bearings — all in motion or assisting motion. The air pumps — ponderous, slow, deliberate; the hot well pump bringing each stroke to a close with a jerk, the main feed pumps, powerful, indefatigable, short of stroke; the little circulating pumps running like sewing machines, joyous, and light; all striving to make the speed, helping the long steel arms to shoot out of their sleeves and turn the cranks one hundred and fifty times a minute or more—inevitable, powerful, superior.

In the fire rooms the scene was no less active. Here the heart of the ship throbs. Furnace doors fly open, men half naked, black with coal dust, dripping with sweat that leaves little white streaks on their skin where it runs down, plunge their shovels fiercely into the heaps of coal on the deck and throw it far

*Photo by International Film Co.

back into the furnaces. With a slam the doors fly shut again and the firemen run their slice bars through a special hole, over the grating, work with the incandescent mass, and pull the bars back, heated in that half minute to a white heat. That is the way it goes in every one of eight fire rooms—eight firemen to each room, all savagely tossing into the hungry furnaces the coal a crew of coal passers haul out of the bunkers in big iron buckets.

The heat is terrific, and when a furnace opens the fires roar, blown to a fury by the forced draught. Each fireman has to protect his hands by a cloth, and sometimes his eyes by glasses, and occasionally he has to jump to the middle of the room for a brief second to get a gust of the air the blowers are forcing down from the decks above.

Then a call comes for more steam. You should see the shovels fly now! The air becomes obscure with coal dust. Clack, clack, clack! The doors fly shut all around. The men toss coal like mad. They forget the heat, their thirst—some are losing their hand cloths. They trample on one another's feet, knock one another with buckets, and bars, unheedful, for the steam must be made to climb. And while the hungry engines are using it up, the wild energy of the men gains a surplus and the pressure goes up—220, 225, 230 pounds!

That is something like what happened a few years ago on a trial trip. Now with a ship almost twice as large, twice as powerful and three times as costly there was a looking forward to the real thrill that was about to be furnished. The memory of the excitement of the past was to be superseded by a more modern and therefore still more nerve startling hair raiser. All the figures available pointed that way. Here was a piece of propelling machinery designed to furnish 33-000 horse-power. The two main generators when turning at top revolutions were reputed to create enough electricity to supply about thirty of the ordinary ship lighting systems. The four motors were supposed to be about as powerful as sixteen average size freight engines. The speed of the turbines was set down at thirty-five revolutions per second and, of course, as the generators were hitched directly to the turbines, they would have to turn at this same dizzy rate. The prospects for a pleasant afternoon were decidely good.

Now, the whole speed trial resolves itself into a series of various runs for the purpose of determining the number of revolutions at certain speeds, fuel consumption at various speeds, and endurance runs for various periods of time. In order not to ameliorate the full effect of what was in store and see only the most intense part of the trial, the Chief was consulted as to what would be the best time to knock off viewing the scenery from the bridge and get into the turmoil below. "Oh, by all means wait for the four-hour full-speed run. Then you'll see this little marine baby at her best. These preliminary runs are nothing at all. Don't waste time on them if you are looking for something to make your spine curl. The four-hour full-speed run will make you lose a couple of nights' sleep."

That sounded good, so accordingly I curbed the prancing steeds of my impatience the first few days, in preparation for the treat I was to have later on. I must say it was not a very difficult thing to do. There is nothing interesting these days in fifteen knots. That seems to be nothing more than what the ordinary speed limits permit in any one horse village. The old Oregon could do that. But twenty-one knots for a battleship like the *Tennessee*, well, that was a dish to tickle the palate of the most jaded excitement chaser.

It is difficult to keep tab on all the runs that a ship makes on an occasion of this kind. It seems that she is forever turning, and tooting her whistle, and giving stand-by signals, and yelling "mark!" over the loud speaking telephones, and steering up and down over that measured mile so accurately designated by pretty little white towers on the shore. After a few days of it, unless you are directly concerned, you lose almost all consciousness of it and forget that it is going on. Especially at this time there was something lacking, it seemed. Something was not going off just according to the accepted standards in cases like this. An ominous lack of vibration appeared to indicate that some trouble was being encountered and that the old girl was not walking along as well as the Chief had hoped. The occasional glimpses obtained of the Chief tended to confirm this opinion. A small, slender man with a sensitive face, he looked as though he carried his New York Navy Yard expression still with him. I felt rather sorry for him. These electrical innovations, these electric drive improvements are no joke.

At a rough estimate we had passed the big hotel which ornaments the outskirts of Rockland so beautifully, about the four hundred and twentieth time. Some sea gulls were gracefully planing through the air waiting for us to come to anchor. The weather was perfect, exactly the sort of a day for an automobile drive. The wooded shore looked extremely inviting. I was just calculating the cost of starting from New York with a flivver and making a two months cruise along this strip of the coast when a messenger came up and said that the Chief wanted to know whether I had changed my mind about going below during the full-power run.

"Great codfish!" I cried, "do you mean to say that the full-speed run is being held now—right now?"

"We are just about half through with it, sir," said the polite messenger.

There was no time to lose. It would take me a little while to get dressed and there was a good deal to see, I imagined. No time was wasted getting to my room and peeling off my good clothes to give way for a

suit of dungarees. Next I wrapped up my neck carfully with an old neckerchief, my shoes I took off for a pair of discarded tennis slippers, my sensitive scalp I protected from the dripping oil by means of a white sailor hat whose rim had been torn off, and to complete my outfit I dug up a pair of automobile glasses to give me the final touch of protection against spurting steam, dripping hot water, and splashing oil. Then I crawled down a hatch on the main deck and, at the bottom of a steep ladder, I met the Chief.

"I'm glad you came," he said, "we are just beginning to hit her up fine. Now you follow me and I'll show you all there is to see." So I followed him.

"Here we are in the forward main generator room," he said, "isn't it wonderful? I looked around and saw a big cylindrical steel casing set off here and there by a gauge or a piece of stray cable.

"Where is your electrician's force?" I asked.

"Over there," indicated the Chief. I saw a couple of men in neat dungarees idling near a ladder. "Seem to be nice boys," I remarked.

"Oh yes," replied the Chief, "we get a good class of men in the navy. Now follow me and I'll show you the pump rooms." We decended another iron ladder. Quite a number of pumps seemed to be gathererd here and some men were wiping pistons with waste. "These are the pumps," explained the Chief.

"You have lovely pumps on this ship," I ventured.

"Oh yes," said the Chief, "there is nothing wrong with the pumps on this ship. Let's go into the motor rooms now." So we went up and down a few more ladders and finally arrived at a spacious compartment, painted immaculately white with all its brass and copper pipes and fittings shining brightly.

"This is the inboard motor room. There are two motors like this, on the port and on the starboard sides. Each of the four propellers has its own motor."

I saw a lot of cables leading up from the center of another large rotary structure, neatly painted, with a few openings screened off with a fine wire mesh. A man was lolling near a small dial. We were standing on a grating, dry, polished, of artistic design. The air was fresh and cool.

"Nice place for a quiet afternoon's study or a breath of fresh air."

"Oh yes," said the Chief. "We have a pretty good ventilating system on this ship. Do you feel like going into the boiler rooms."

I wanted the whole works or none, so we passed through two air locked doors and down another ladder till we came to the boiler and fire room.

"How many burners have you lit?" he asked a young fellow standing watch over an indicator. "Four, sir," came the response.

"They're holding two in reserve," commented the chief.

"The oil seems to burn well," I annotated.

"Oh yes," said the Chief, "once you get your burners spraying well and keep five or six inches air pressure in the firerooms, there's nothing to it. I guess we'd better take a look at the control room now."

We made our way along several narrow passageways and finally entered the control room through a small door. This was a long narrow space running athwartships. From a line running through the center of it rose a dozen or so of long levers. On the bulkhead facing them were several dozen indicator dials, gauges, clocks, and various recording instruments. A few officers dressed in neat white collars and some civilians were watching the different hands and pointers.

"This is the vital part of the ship," said the Chief, "here all the movements of the ship are controlled." Some of the officers and civilians seeing me, moved to one side as if afraid of getting dirty. It reminded me that I was rather alarmingly dressed. The goggles I had discarded some time back.

"These gentlemen seem very much interested in their work. We are probably disturbing them. Let us go and, as the time seems to be flying, let us get down to cases and proceed directly to the most exciting spot—where the tension of the full power run is at its greatest—where men are working with over taut nerves—where the activity of the mechanism is focussed to its greatest speed, where"—the Chief looked at me in amazement.

"Why, we were in the main generator room an hour ago. There is nothing left to show you. Besides the run is almost completed. They told me in the control room we haven't gone below twenty-one knots so far."

He started away and I followed. On the way out I saw a man carrying an oil can.

"Wait a minute, young fellow," I said, "lend me your can for a second." I took it and squtrted a few jets over my shoes, on my coat, and rubbed a little on my hands and face. Then I went up to my room and removed my oil drenched overalls. After I was dressed again in my normal belongings I stepped out on the deck. The Chief was just coming down from the bridge. His face wore a smile. "The run is finished. Everything went fine. Gosh, but I'm glad it's over. I can't stand the excitement of it like I could formerly. But the romance of it—ah, that I guess I'll never lose. Wasn't it wonderful below—all that ponderous, gigantic mechanism grinding out the power to shoot this ship through the water twenty-one point zero two knots per hour. Collossal!"

"Great hiccoughing hyena!" I gasped, "let me have air!" In an instant I was up on the bridge. The officer of the deck was taking a bearing. "Do you mind if I stay up here and watch the scenery move by? I love excitement—the thrill of motion. It's great up here."

"Go to it," he grunted, "but if you're looking for excitement, the thrill of motion as you call it, why in the devil didn't you go below while they were making their full power run?"

General Arrangement of Propelling Machinery of the U. S. S. Tennessee

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Although the *Tennessee* is the second battleship to have electric propelling machinery, it is the first to realize the full advantages of the electric system of propulsion in regard to arrangement of machinery. The ship has a displacement of approximately 33 000 tons; a length overall of 624 feet, and a breadth of 97 ft., 3.5 inches on the load water line. The normal full-load speed is 21 knots and the calculated horse-power under this condition is 28 000.

The *Tennessee's* armament consists of a main battery of twelve 14 inch guns; a secondary battery of fourteen 5 inch guns, four 3 inch anti-aircraft guns, four 6-pounders for saluting, and two 21 inch submerged torpedo tubes.

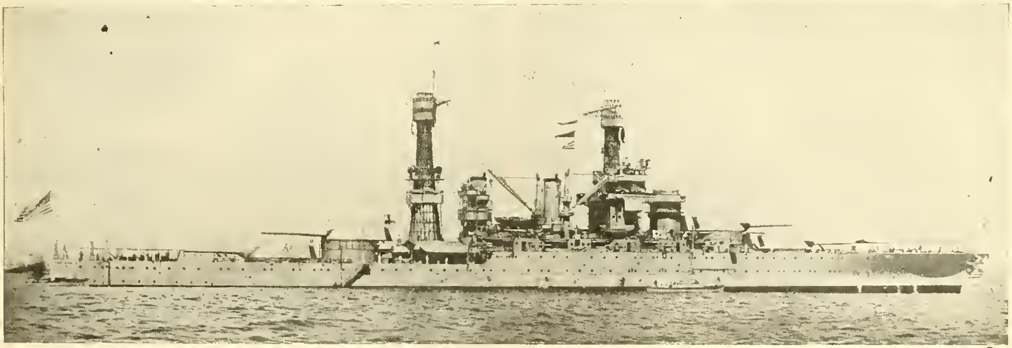

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FIG. 1—UNITED STATES BATTLESHIP TENNNESSEE

The propellers are driven by four direct-connected, two-speed, wound-secondary induction motors, supplied with three-phase power through suitable control equipment at approximately 3400 volts, and 34.6 cycles, (full speed) by two direct connected 2075 r.p.m. turbogenerators. A battery of eight oil-fired water tube boilers supplies steam to the turbines at 280 lbs. gage at the boilers. The generators are excited from one of the 300 kw direct-current geared turbine auxiliary sets, through a booster so designed as to vary the 240 volt bus voltage in either direction to a value best suited for the given condition. All engine room auxiliaries necessary to the main propulsion, such as the main and auxiliary condenser, circulating and condensate pumps, the lubricating and governor oil pumps, oil cooler circulating pumps, and the main motor ventilating blowers are driven by direct-current motors supplied with power from the same generator which is used for excitation. One auxiliary generator in each engine room is sufficient to supply the excitation and auxiliary load just mentioned.

The power generating machinery is located in two engine rooms, one being forward of the other, and both forward of the control room. The turbogenerators are mounted directly above the condensers. In each engine room, there are two 300 kw geared turbine condensing, and one non-condensing direct-current sets of the three-wire type, supplying power at 240 and 120 volts. These sets are mounted on the same flat as the main turbogenerator sets, as is also the motor generator booster. The condenser with its auxiliaries is located in the lower machinery flat or pump room, directly underneath the main generators. The switchboards for the 300 kw sets are located at the ends of the engine rooms.

The control room contains all the control equipment and other apparatus necessary for the complete control of the propelling machinery and is located aft of the after engine room and between the two outboard motor rooms. The inboard motors are in what is known as the center motor room, located directly aft of the control room. All of the main machinery is located in separate water tight rooms, as shown in Fig. 2.

The cables connecting the units of the main propelling machinery are of the three-conductor, lead covered type. There are a sufficient number of these cables in parallel to carry the maximum power safely. The cable ends are provided with pot heads forming water-tight seals from which the respective conductors are brought out and connected to well-insulated bus structures located over the switches in the control room, and at the motors and generators.

From maximum speed down to a speed slightly in excess of 16 knots, two generators are used, and the motors are connected to the 24 pole winding. Speeds below this are obtained with only one generator in operation and the motors connected to either the 24 or 36 pole winding. Speeds up to and including 15 knots can be obtained with the motors connected to the 36 pole winding.

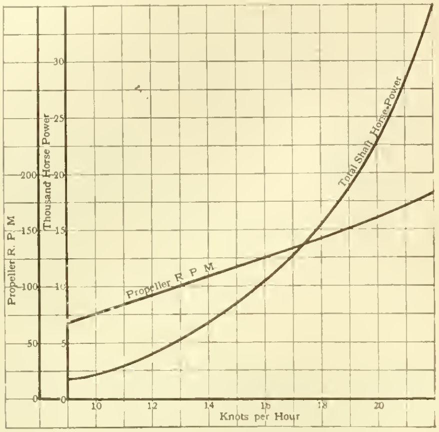

FIG. 2—PROPELLOR PERFORMANCE CURVES

By providing two sets of windings on the motors, it is possible to obtain more economical operation at low speeds than would be the case with a single winding. As the propeller speeds are adjusted by regulating the speed of the turbines, the two-winding arrangement permits the turbines to be operated at high speeds over the cruising range as well as the full speed range, thus resulting in better economy.

MAIN MOTORS

Each main propelling motor is capable of delivering a maximum of 8375 hp, at a speed of about 185 r.p.m. They are of the induction type and are wound for two speeds at full frequency, there being a 24 pole and a 36 pole winding. The primary or stator has two independent windings, one for each set of poles. The rotor has a three-phase, two-parallel star-connected winding having balancer connections operating as such on the 24 pole winding. The 24 pole winding is connected to three slip rings. When the stator is connected to the 36 pole winding, the balancer connections form short-circuit paths for the rotor conductors, thus forming an ordinary squirrel-cage winding having straps instead of resistance rings to connect the rotor conductors together.

In general, the design of the motors follows standard land practice. There are, however, certain features, particularly in connection with the insulation of the windings that have been given special consideration to guard against the deleterious effect of salt and moisture conditions. The insulation is of the best known material and is applied and treated in accordance with thoroughly tried methods.

The mechanical construction of the motor is of the self-contained type, in which the bearings are carried by suitable brackets which fit into recesses in the stator frame. The entire motor is supported by feet cast integral with the frame on either side. The bearing housings are adjustable radially by means ot jack screws in the brackets and, after being adjusted, are bolted rigidly to the bracket.

The ventilation is supplied by duplicate direct-current, motor-driven exhaust blowers, each capable of delivering 12 500 cubic feet per minute maximum. In addition to these separate blowers, the rotor itself is provided with fan vanes which assist in the ventilation, and which are capable of supplying sufficient air to enable the motors to be operated for brief periods at full load in case of failure of the blowers. The blowers are mounted on the top of the motors, and draw the air through the motor and discharge it through suitable ducts to the deck. The system of ventilation consists of the axial flow of air through the core and end windings, the air being drawn in through openings in the brackets and discharged through a radial duct at the middle of the core to an outlet at the top of the motor, and from there to the deck.

In order to get at the motors for inspection and repair, suitable tracks and disassembling gear are provided, so that the stator can be moved to clear the rotor windings.

MAIN GENERATORS

Each main generator is capable of delivering a maximum of 15 000 kv-a at approximately 30.5 cycles. The generators are designed and constructed in accorddance with standard land practice, except that the rotor is of the totally enclosed type. The stator coils are insulated in the same manner as the motor coils.

The air for ventilating the generators is supplied to the machinery space by means of separate ventilat-

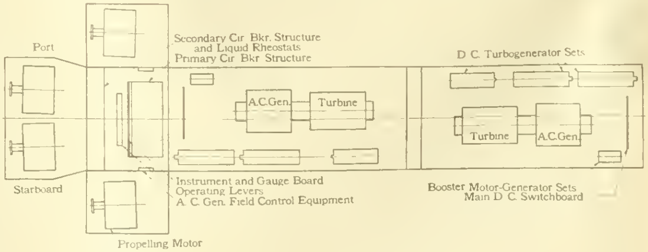

FIG 3 SCHEMATIC PLAN OF ARRANGEMENT OF PROPELLING MACHINERY

ing blowers. The air is drawn from the lower machinery space through an inlet at the bottom of the generator, through the end bells, entering the machine at each end of the rotor. From there, it is forced

through the end windings, core and air-gap axially, and discharged radially through a central opening in the core, from whence it passes through a duct to the deck.

The rotor consists of a solid steel forging having radial slots for receiving the windings. The winding consists of a series of turns of bare copper strap and the insulation is entirely mica and asbestos. After winding, the coils are very substantially braced, in order to prevent any possible movement.

The main motors and the generators are each provided with thermocouples for measuring the hot spot temperature. These thermocouples are all connected to a potentiometer board in the control room.

In order to prevent the motors and the generators from sweating when idle, heaters are provided, the motors being warmed electrically and the generators by steam coils. These coils are so located as not to cause local heating and all joints and connections to the coils are made outside of the frame of the machine to avoid the possibility of steam leaks into the machine.

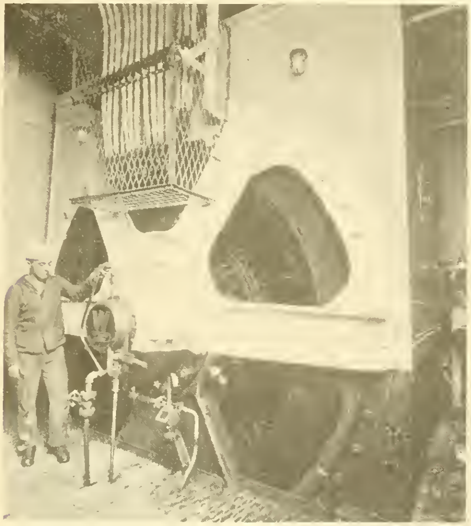

FIG. 4—STARBOARD INBOARD PROPELLING MOTOR

TURBINES

The turbine is of the combined impulse and reaction semi-double-flow type, allowing complete expansion of the steam in one cylinder. An exhaust connection is provided at each end of the turbine.

The speed is regulated by the governor valve only, hand valves being used merely to obtain the best economy and to prevent overloading the boilers at the various standard speeds.

Briefly, the speed-control system consists of a governor driven directly from the turbine shaft through suitable gearing. The governor is essentially a dead weight governor, in which the dead weight is replaced by a hydraulic piston, resulting in a type of governor capable of functioning over a wide range of speed by varying the hydraulic pressure on the piston. The speed is adjusted hydraulically by means of a control valve in the main control room which regulates the oil pressure. A double-seated poppet valve located on the main steam inlet to the turbine is controlled through a floating lever oil pressure relay system from the main governor, and this valve controls the amount of steam as required to maintain the speed for which the system is set. The governor control valve is also operated through a suitable oil pressure relay by a separate over-speed governor secured to the end of the turbine shaft. In addition, this over-speed governor also operates the main throttle valve, in case of necessity.

In order to limit the power input to the turbine on overload conditions to an amount which will prevent excessive overloads on the machinery and also prevent priming of the boilers, a power limit stop is provided. This is arranged to limit the travel of the governor linkage in the direction which admits more steam. The position of the stop is adjusted electrically from the main control room through a system of gearing operated by a small motor. In order that the operator may know the position of the power limit stop at any instant, an electrical position indicating system is provided, the transmitter of which is driven by spur gearing from the power limit stop mechanism. The indicator is mounted in the control room.

FIG. 5—ENGINE ROOM AND MAIN GENERATOR

In operation, this system functions as follows:—The speed of the ship is set from the control room for any given standard by means of the hydraulic speed-control system. The power limit stop is then adjusted to limit the motor speed to a few revolutions above that corresponding to the standard speed. Should an overload occur from turning or from any other cause, the speed-control governor will tend to maintain a constant speed by admitting more steam. However, as the governor linkage has only an additional limit of travel corresponding to the few revolutions increase in motor speed, the steam which can be admitted to the turbine is therefore limited, and consequently the overload has a fixed value for any given condition.

The power-limit stop may also be used for adjusting the speed of the turbine below any value for which the main speed governor system is set, and it accomplishes this in a manner similar to throttling. Since the speed is a function of the oil pressure, oil gauges mounted in the control room give a further check on the proper functioning of the entire turbine control system. The over-speed stop may be operated from the over-speed governor, hand trip in the engine room or by wire pull from the control room.

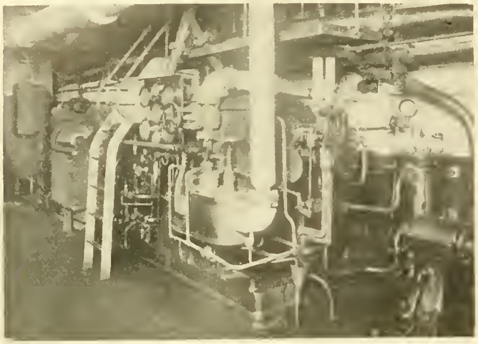

FIG. 6—300 KW DIRECT-CURRENT GEARED TURBINE SET

The turbine and generator bearings have forced lubrication. Oil for the governor control system is also supplied from the same system. The oil is delivered to the governor system at 80 lbs. pressure and to the bearings at 5 to 10 lbs. pressure through a reducing valve. The oil pumps for circulating this oil are of the positive displacement rotary type. Two pumps are provided in each engine room, one of which is motor driven and the other turbine driven, the latter standing by as a spare. However, upon failure of the motor-driven pump from any cause, an arrangement of pistons operated by the oil pressure will automatically cause the turbine-driven pump to be placed in operation. The turbine-driven pump is provided with a constant speed governor and an overspeed stop.

MAIN CONTROL

As in the case of any other drive, the control for the electric drive is operated under orders from the bridge. All controlling apparatus necessary for the operation of the propelling machinery is located in the control room, and all operations for the control of the ship are effected in this room, except the actual starting of the turbines. The circuits are handled by means of manually-operated oil circuit breakers. All circuit breakers are of sufficient capacity to open the circuits under full power and voltage conditions, although in normal operation, circuit breakers are not opened or closed under load. They are manually operated from levers which are located directly in front of the contront room switchboard, and arranged so that the operator faces forward. These levers are interlocked so that improper operation is impossible. The primary circuit breakers are arranged in two rows athwart ship having an aisle between them for inspection and repair, if necessary. The secondary short-circuiting breakers, and the liquid rheostats for controlling the motor secondaries, are located back of the operating aisle.

In order to disconnect any circuit completely, self-contained disconnecting devices have been provided on the reverser circuit breakers, generator circuit breakers, and tie circuit breakers. The mechanism is so arranged that the circuit breaker must be opened before it is possible to disengage the disconnecting device. This provision safe-guards the men in case of improper or faulty operation, and at the same time makes it possible to inspect or repair a circuit breaker while the ship is under way.

The levers operate the circuit breakers and rheostat valves in pairs, and are arranged in a single row, directly aft of the circuit breaker structure. The arrangement is symmetrical so that levers on the left of the central position operate the circuit breakers in the after generator and port motor circuits, while those on the right of the central position operate the circuit breakers which control the circuits of the forward generator and starboard motors. The pedestals on which the turbine control valves are mounted and the generator field switch levers are located in the center of the group. All the levers are mechanically interlocked so as to insure the proper sequence of operation. The scheme of interlocking is such that the field must be off and the steam control reduced to a low setting before any of the above circuit breakers can be operated.

With two generators in operation, the control of the port and of the starboard side of the ship are independent.

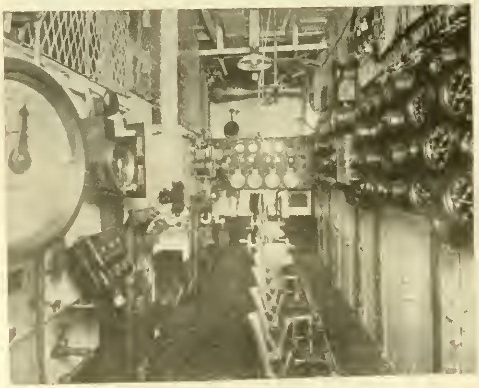

FIG. 7—GENERAL VIEW OF CONTROL ROOM

With the tie circuit breaker closed and one generator in operation, the direction of rotation of port and starboard screws may be in the same or opposite directions, but of necessity must be at equal speeds.

All starting and maneuvering is done with the 24 pole connection. When the motors are thus connected the secondaries are controlled by means of liquid

rheostats. There is one double rheostat for the port motors and one for the starboard motors. The rheostat consists essentially of a two-compartment tank, the lower compartment of which serves as a reservoir for the electrolyte and also as a container for the cooling coils, while the upper compartment contains the electrodes. When it is desired to use a rheostat, the valve in the upper compartment is closed by means of a lever operated from the control stand, thus allowing the liquid to rise in the upper compartment. After the maximum level has been reached, the motor secondary is completely short-circuited by means of an oil circuit breaker which is operated by a lever from the control stand.

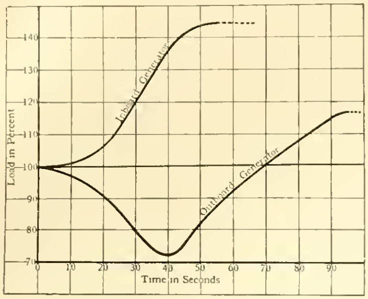

FIG. 8—LOAD ON GENERATORS WHEN TURNING WITH 35 DEGREE RUDDER
Power limit not set.

OPERATION

The problem involved in designing equipment for battle ship propulsion is entirely special, and quite different from that encountered in designing land power plants. The generators, turbines, motors and control must be considered as a unit, and due regard given to the requirements of the propeller. The starting and running requirements under normal sea conditions are not severe, as the power required is practically steady. In a rough sea, the power varies considerably and is unsteady. The most severe conditions, however, are obtained during reversal and during turning, and if precautions are not taken to limit the power output of the turbine, it is possible to impose large overloads on the machinery during the latter condition. Fig. 8 shows the manner in which the inboard and outboard sides vary when making a turn with a 35 degree rudder. By "inboard" side of the turn is meant the side toward the center of the circle described. The particular curve shown has been interpolated from tests made on a modern battleship making 19 knots and turning with a 35 degree right rudder. The test in this instance was made without setting the power limit stop and the turbines were allowed to take any load which may be imposed up to the maximum capacity of the machine. It will be noted that the power of the generator supplying the inboard side increases rapidly during the first 50 seconds, at which point it reaches the maximum output of the turbine. The power delivered by the outboard turbine, however, decreases rather rapidly during the first 40 seconds, and then begins to increase rapidly until a constant value is reached at about 90 seconds. An analysis of the curve shows that the inboard side developed an overload of approximately 45 percent when the maximum power of the turbine was reached and that the inboard side dropped to about 75 percent normal at the end of the first 40 seconds and then increased to a value corresponding to approximately 15 percent overload at the end of 90 seconds, when the power became constant. These conditions are common to all ships, but vary in the relative proportions of overload.

It is evident that, if precautions are not taken to prevent such overloads being imposed on the machinery, it would be necessary to carry sufficient excitation on the generators continuously to take care of these overloads. At reduced loads, it would be possible to carry this additional excitation, but it would result in uneconomical operation. To provide for similar conditions at the maximum loads would necessitate an unwarranted reserve capacity in the generator fields, thus resulting in larger generators than needed. However, to overcome this condition, a form of power limit stop is provided, the function of which is to limit the amount of steam taken by the turbine to a predetermined value, which under normal operating conditions corresponds to an overload of about ten percent. By thus limiting the amount of load that can be taken by the turbine, and consequently the generator, the field excitation can be reduced to a value just sufficient to maintain the generator voltage safely under the overload condition. The only effect of thus limiting the power is a slight and inappreciable slowing down of the ship during such maneuvers. The economy gained, however, is of considerable advantage.

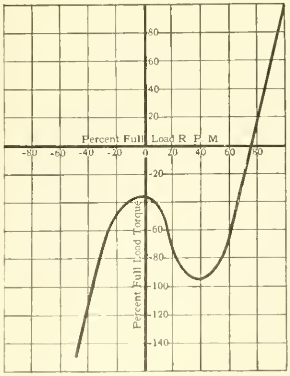

FIG. 9—PROPELLOR TORQUE CHARACTERISTICS
When reversing the propellor with the ship going ahead at full speed.

The shape of the turning curves and the overload obtained varies with different ships, as also does the

relative excitation to be carried on the generators. It is, therefore, necessary to conduct a series of "drop out" tests on each ship in order to determine the minimum safe field current which should be carried continuously to enable the ship to be maneuvered without liability of the motors and generators pulling apart. Ordinarily, motors of normal design have inherent torque characteristics which are sufficient to cope with these conditions, providing the generator voltage holds up, but since it is a characteristic of the generator voltage to suddenly break on abnormal loads, the condition is purely one related to the generators.

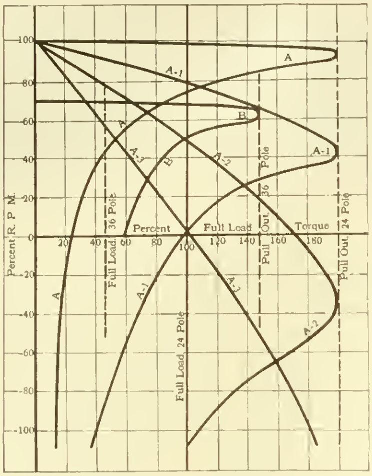

FIG. 10—PROPELLING MOTOR SPEED-TORQUE CHARACTERISTICS

A—24 pole connections, with wound secondary short circuited. A-1; A-2; A-3—24 pole connections, with external secondary resistance. B—36 pole connections, squirrel-cage secondary winding.

In order to provide indication of the condition of stable or unstable operation, stability indicators are arranged in the generator circuits. As these instruments indicate the relative ratio of generator armature current and voltage, they will indicate clearly when the point of voltage collapse is being approached.

Another condition involving the correct performance of generator, motor and control is that which exists during reversal. These conditions are shown in Fig. 9. The relative proportions of these curves also depend upon the ship in question, but the curves shown can be considered as typical of the backing conditions. For the sake of clearness, the reversing curve and the motor speed torque characteristics have been shown separately. As the motor is of the wound secondary type with adjustable external resistance, it is possible to vary the torque curves to suit the operating conditions. Furthermore, since the rheostat is of the liquid type, it is possible to get an infinite number of speed-torque curves. A few typical speed-torque curves have been drawn for different values of secondary resistance. An inspection of Fig. 9 will show that the speed of the propellers drops to approximately 75 percent when the power is taken off. At this point, the motor connections are reversed, and the motors caused to produce a torque opposing the turning effort produced by the motion of the ship on the propellers. It will be noted that, as the r.p.m. of the propellers decrease, the opposing torque builds up to approximately full load value at 40 percent ahead revolutions and then decreases to approximately 35 percent when the propellers are brought to a stand-still. As the propellers are reversed, the torque increases rapidly and reaches full load value at 40 percent r.p.m. in the backing direction. The above discussion is based on maintaining full speed of the ship. Under actual conditions, however, the ship slows down considerably in the time taken to reach 40 percent r.p.m. in a backing direction, and therefore higher rotational speeds of the propellers in the backing direction can be obtained before reaching full-load torque.

The most vital part of the curve is that at about 40 percent of full load speed when bringing the propellers to a stop condition. In the case of wound-rotor motors, this condition presents no difficulties, as it is possible to obtain torques considerably in excess of normal full-load torque at any speed by simply adjusting the external resistance. The generators, however, must have sufficient field capacity to furnish the voltage required to maintain the torque under the conditions stated. In the case of squirrel-cage motors, however, it would be necessary to introduce special designs, to obtain speed-torque curves which would enable the motor to deliver torque safely in excess of the requirements under the conditions of operation described.

All such conditions, of course, must be taken into account in designing the propelling equipment and it is obvious that turbines, generators, motors and control must be designed as a unit in order that each will have characteristics which are sufficient to enable all parts of the equipment to function properly under the required conditions.

The Propelling Motors of the U.S.S. Tennessee

H. L. BARNHOLDT
Motor Engineering Dept.,
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IN THE type of ship propelling machinery employing steam turbine driven alternating-current generators and propelling motors it is possible to obtain all the speeds necessary to maneuver the ship by simply adjusting the speed of the turbine, thus changing the generator frequency and the speed of the motors. Since these motors form the only load for the generators, varying the primary frequency is entirely feasible, although by this method the steam economy becomes poor at the lower speeds. This is not a serious drawback in case of passenger liners, cargo boats, etc., which usually run at their top speed and for such ships that method of speed control is thoroughly practicable and economical. For warships, however, the requirements are different, and in the case of capital ships, the specifications of the U. S. Navy Department call for the maximum attainable steam economy at one lower speed for use in long distance cruising as well as at full speed. The importance of economy at lower speeds in the case of a battleship becomes apparent when we consider that the power taken by the propellers varies approximately as the third power of the ship's speed, so that, for example, if the same steam consumption per shaft horsepower could be maintained at half speed as at full speed, the ship could travel four times the distance at half speed that she could at full speed using the same amount of fuel. The two speeds in question for the U. S. S. *Tennessee* and the six other battleships of her class were set at 21 and 15 knots respectively, and since for reasons of steam economy it was essential to operate the turbine at or near its full speed under both of these conditions, an induction motor having two synchronous speeds was adopted as the only logical solution. A pole combination of 24 and 36 poles was chosen, which corresponds to propeller speeds at 21 and 15 knots, both being obtained with practically full speed on the turbine. This pole combination also permitted the use of a type of rotor winding, as described later, by means of which both numbers of poles were obtained with a single winding connected to three slip rings.

PROPELLER TORQUE CHARACTERISTICS

Aside from the question of fuel economy when the ship is under way, there are also certain vital requirements to be met when maneuvering. First among these are the peculiar torque characteristics of the propeller when making a quick stop or reversal of the ship, at which time it may be necessary for the propellers to pass from full speed ahead to full speed astern while the ship itself is still going ahead. In examining these conditions* and their relation to the motor design it becomes apparent that, in order to stop the propellers with the ship making full speed ahead, the motors must be capable of delivering the full ahead torque, with a proper margin of safety, when operating at a slip of approximately 140 percent. This requirement can be met by inserting the proper amount of resistance in the rotor circuit and a careful analysis was made to determine whether to put this resistance into the rotor winding proper, which would permit of a squirrel-cage motor being used, or to place it external to the rotor, necessitating a slip-ring type of motor. After making up tentative designs of both types of machines it developed that, by employing a special type of squirrel-cage winding, a motor could be built that combined the requisite high torque characteristics during reversal with a low slip and high efficiency at full load. While such a machine would be relatively simple from the standpoint of control, it was found that the heat generated in the rotor windings during a quick stop or reversal of the propellers was of such magnitude that, to make proper

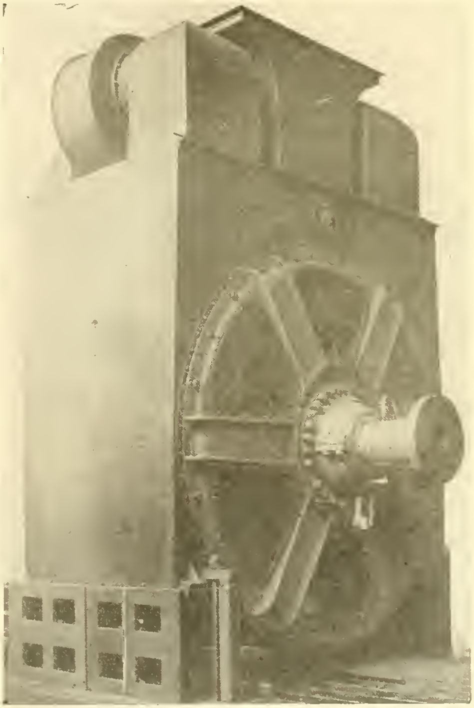


FIG. 1—ONE OF THE MAIN PROPELLING MOTORS FOR THE BATTLESHIP *Tennessee*

*See article by Mr. W. E. Thau, Figs 9 and 10, p. 249, this issue.

provision for heat storage and to take care of the linear expansion and contraction of the rotor winding caused by changing temperatures, would necessitate special construction entirely beyond the limits of experience. Owing to the importance of the application, this was a serious objection. On the other hand, the slip ring type of machine permitted this large extra amount of heat to be absorbed in the rheostat, away from the motor, which naturally tends towards greater reliability. Furthermore, the squirrel-cage motor showed a poorer power-factor under all conditions of load. All in all, the preponderance of advantages appeared to be with the slip ring type of motor, which was consequently adopted.

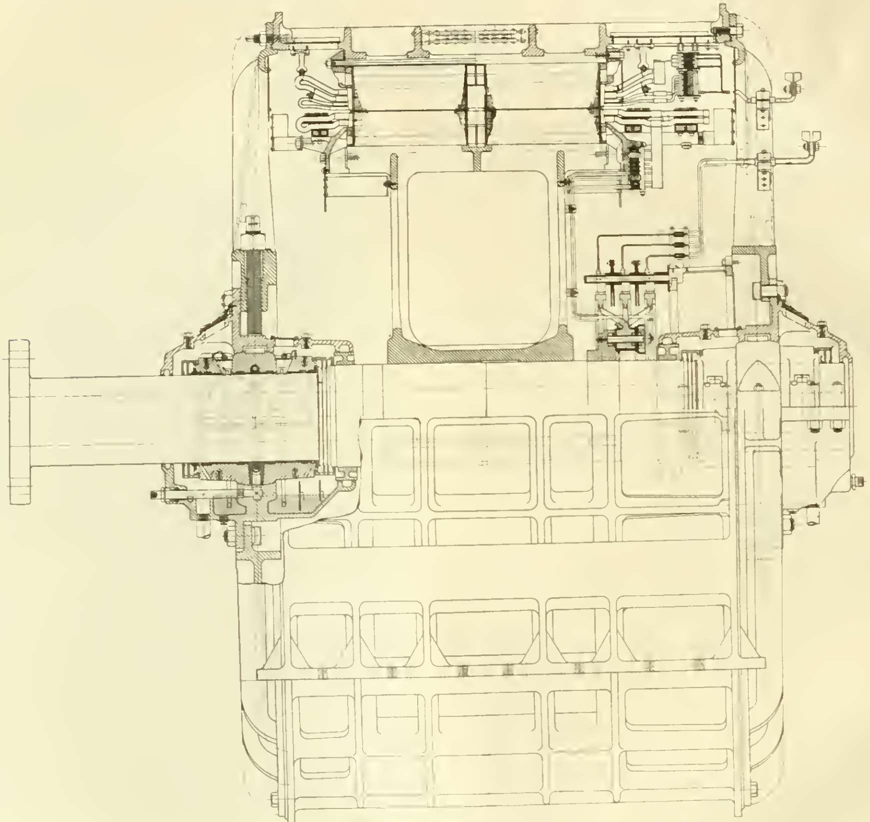


FIG. 2—GENERAL ASSEMBLY OF PROPELLING MOTORS

RATING

The power specified for driving the propellers of the *Tennessee* at her full speed and cruising speed was 28 000 shaft hp, 170 r.p.m. at 21 knots and 8500 shaft hp, 118 r.p.m. at 15 knots. There are four propellers, each driven by one motor, arranged for two synchronous speeds. The full rating of each motor at 21 knots is 7000 hp, 34.6 cycles, three-phase, 24 poles, 170 r.p.m., 3270 volts, and at 15 knots it is 2125 hp, 36.2 cycles, three-phase, 36 poles, 118 r.p.m., 3250 volts. There is also required a maximum capacity for each motor of 8375 hp at 180 r.p.m. Propeller speeds intermediate between and below those given above are secured by controlling the speed and frequency of the turbine-generator, there being a special governing mechanism provided on the steam turbine for this purpose.

At speeds up to 15 knots, the motors operate normally on the 36 pole connection, the total power being supplied by one generator. Above 15 knots the 24 pole connection is used on the motors and still only one generator is required up to and including 16.1 knots, above which speed it is necessary to use both generators. The motors and control are arranged so that all starting and reversing is normally performed with the motors on the 24 pole combination. A fortunate coincidence, which was taken advantage of in this connection, is the fact that as soon as the power is taken off the motors the speed of the propellers drops to about 75 percent of the previous speed. Therefore assuming that it is desired to get under way and to make a certain speed on the 36

pole connection, the motors are first brought up to that speed on the 24 pole connection. Then, as the power is taken off the motors for switching to the 36 pole connection, the speed of the propellers drops to 75 percent or to a point nearly corresponding to the 36 pole speed.

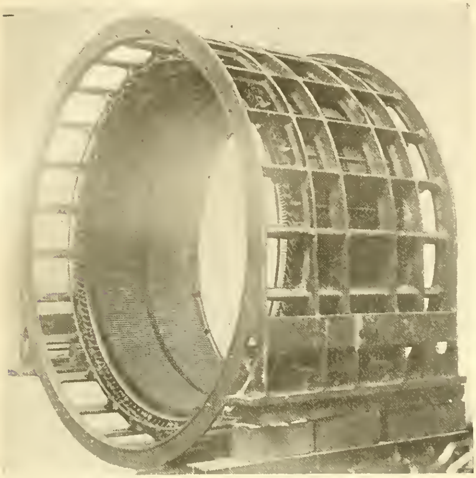


FIG. 3—STATOR CORE READY FOR WINDING

The advantage of this is that the motors can be changed from 24 pole to 36 pole operation with the steam turbine running at practically the same speed, thus insuring that the motors and generators will be brought into step quickly and without excessive strain on the windings during the switching operation. As soon as the motors and generators have come into step, they are brought up together to the desired speed.

To design a motor of this rating suitable for marine work is a problem quite different from ordinary land practice. The weight must be kept to a minimum, the available space is restricted and these conditions must be met without in any way handicapping the factor of reliability, the paramount requirement of this application. In order to obtain the lowest weight practicable, the active material was reduced by employing forced ventilation, while the mechanical parts were made light in weight, and yet of ample strength by employing steel for practically all the castings. With foundations of the character available on shipboard a bracket type of motor was practically the only choice. The bracket bearing construction, however, serves admirably to keep the shaft in line and to maintain proper running clearance between stator and rotor, and it goes far towards obtaining the required strength and rigidity of the machine as a whole, combined with low weight and minimum of space. In order to gain full access to all parts of stator and rotor windings, the foundations for the motor are extended to permit sliding the stator forward a distance sufficient to expose the rotor completely. To accomplish this it is necessary to loosen the after bearing bracket, to remove the upper half of the forward bearing and to support the shaft, for which purpose a set of lifting gear is provided in each motor room.

STATOR

The necessary strength and rigidity required of the stator are obtained by using a one piece, cast steel frame of ring and web construction, with supporting feet extending across the entire length and cast integral with the frame. A groove is planed in the under side of each foot and there is a corresponding key on the foundation track in the ship, the purpose of this arrangement being to keep the stator parallel to, and clear of the rotor, when sliding the stator forward in order to gain access to the internal parts of the machine. Jack screws are provided in the stator feet for the purpose of raising the stator slightly so as to introduce lubricants between the feet and the foundation tracks preparatory to sliding.

The laminations are dovetailed into ribs in the frame casting and are clamped between heavy end plates with fingers for supporting the teeth. The slots are of the straight open type and the coils of each winding are completely formed and insulated before being placed in the slots.

In choosing a stator winding arrangement for the purpose of obtaining two synchronous speeds, two methods presented themselves, viz., to use either a single winding with suitable connections for both 24 and 36 poles or else one complete winding for each number of poles. After investigation, including the making of many tentative designs, an arrangement using two independent windings in the stator was chosen as being preferable to a single winding, owing mainly to the complicated system of connections necessary with the latter and also due to the fact that with a single stator winding, connected for both 24 and 36 poles, it would be impracticable to cut out individual coils from the stator

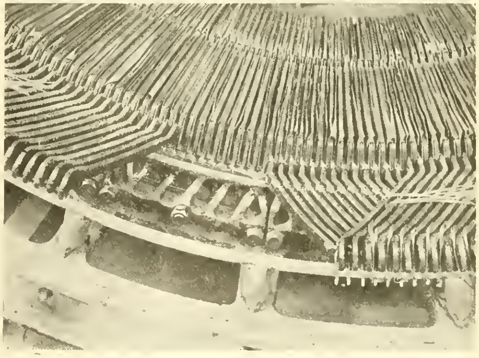


FIG. 4—THE 24 POLE WINDING DURING ASSEMBLY

winding, which is a generally accepted and quick method of putting the motor back in service in case of a local breakdown. Each slot contains two coil sides of each winding, the 24 pole coils being located at the bottom of the slot.

In order to withstand the adverse atmospheric conditions incident to marine service, it is necessary that the insulation of the windings should be the best obtainable. This applies particularly to that part of the winding which is imbedded in the core, the so-called straight part of the coil, and the solution of the problem here lies in the use of mica. Mica possesses an admirable combination of great dielectric strength and high heat resistive qualities, in fact its insulation resistance increases with the temperature. It is also resilient and retains its resiliency indefinitely, thus helping to hold the coils tightly in the slots. For the purpose of applying it on the coils, the mica laminae are pasted to a very thin paper to give it the necessary mechanical support and the mica on the side opposite this paper binder is covered with a coating of shellac. This sheet is then wrapped around the straight part of the coil, at first

FIG. 5—ALL OF THE 24 POLE WINDING IN PLACE

loosely by hand, whereupon the coil is placed on a machine, which securely holds it and has two or more electrically heated plates which revolve around the coil, softening the shellac bond and exerting a uniform pressure, thus slipping and tightening the wrapper around the coil until the insulation takes on the character of a compact wall of mica.

The curved ends of the coils projecting outside of the core, where the demands on the insulation are not so great, and where more flexibility is required, are insulated with treated cloth in the form of narrow tape. To guard against salt or moisture it is essential that all joints in the insulation be effectively sealed, which is best accomplished by repeated varnish treatments. Not only are the joints given several coats of varnish individually as they are made, but the entire winding, when completely assembled and connected, receives six treatments of varnish, the entire stator being baked in an oven after each of these treatments. The coils are held in the slots by means of bakelite micarta wedges

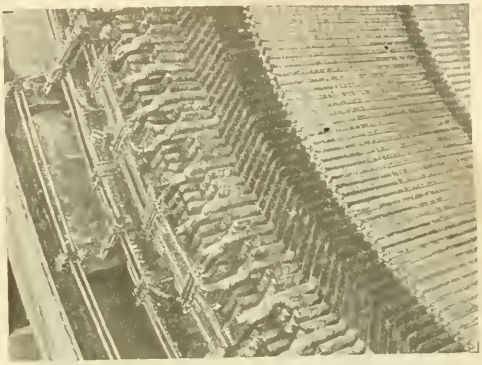


FIG. 6—A PORTION OF THE STATOR COMPLETELY WOUND AND CONNECTED

driven into grooves at the top of the teeth, while the coil ends are braced by lashing the individual coils to an insulated steel ring, rigidly supported from the stator frame.

The stator is provided with six thermocouples, three for each winding, located in the slots between top and bottom coils for the purpose of measuring the hot spot temperature of the stator windings.

In the lower half of the stator a series of direct-current electric heaters are fitted for use when the motors are idle for any considerable length of time. The purpose of these heaters is to keep the temperature of the motors slightly higher than that of the surrounding air, thereby preventing sweating or the formation of

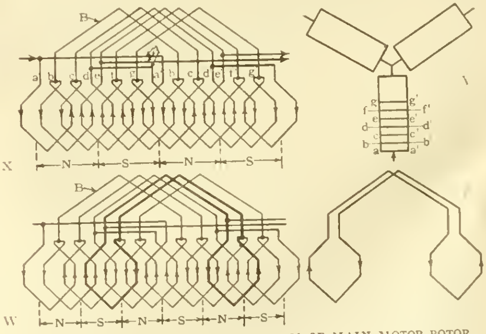


FIG. 7—SCHEMATIC WINDING DIAGRAM OF MAIN MOTOR ROTOR

Showing novel method of connections by means of which the 24 pole phase winding automatically becomes a short-circuited winding for 36 pole operation.

condensate in the motor, which otherwise might occur and possibly cause damage to the insulation.

ROTOR

The rotor must be designed to transmit the torque of the motor under all conditions of load. Also it must

be capable of being reversed from full speed and at full line voltage, or even in excess thereof, when required to make a quick stop or reversal of the propellers, and to withstand the severe insulation and mechanical strains imposed by that operation. For that reason, the rotor

FIG. 8—ONE GROUP OF THE SPECIAL ROTOR CONNECTORS

is built up on a strong, rugged double-arm spider, made of cast steel in one piece and securely pressed on and keyed to the shaft. The laminations are dovetailed into the spider and clamped between heavy end plates with fingers for supporting the teeth. These end plates also form a support for the projecting coil ends. The punchings have overhung slots with openings sufficiently large to allow the assembly of coils completely formed and insulated beforehand, thus retaining the advantages of a straight open slot construction without sacrificing the superior performance characteristics inherent in the partially closed type of slot.

While the stator is wound with two independent windings, one for 24 pole operation and one for 36 pole operation, the rotor is wound with only one three-phase winding, permanently connected to three collector rings. This winding is adapted for either 24 pole or 36 pole operation by means of a novel method of connection. Referring to Fig. 7, the view at *X* represents a section equal to one-sixth of one phase of the rotor winding. The coils are arranged in groups and by means of group connectors *A* are connected for 24 poles in two parallel circuits, which are joined in star as indicated at *V*. Therefore, with the stator connected for 24 poles, the machine will operate in the usual manner for induction motors having phase-wound rotors, permitting suitable external resistance for starting or reversing to be inserted in the rotor circuit. There being two parallel circuits, it follows that certain points of the two circuits will have the same potential. The groups of coils are arranged in such a manner as to locate these equi-potential points at a and a′, b and b′, c and c′ etc. and these points are joined together in pairs by special connectors *B*. When the motor is operated on 24 poles, these connectors do not carry any load current since they join together points having the same potential.

When, however, the 36 pole stator winding is energized, the conditions change, as shown in the view at *W*, representing the same section of the rotor winding as at *X*, so that in the space occupied by four poles in the view at *X* for the 24 pole connection, the stator winding when connected for 36 poles will produce six poles as indicated by arrows at *W*, which indicate the direction of the e.m.f.'s of the several coils. The special connectors *B* now serve as short-circuits, connecting pairs of coils together in series with their e.m.f.'s added. Such a pair of coils is indicated by heavy lines in the view at *W* and separately in the view at *Z*. The entire rotor windings being thus connected with all the coils short-circuited in pairs, the result is that the motor on the 36 pole connection will have characteristics similar to those of a squirrel-cage type of induction motor. Due to the relatively large distance between the two coils in each short-circuited pair, a slight magnetic balancing action is obtained, similar to that on a squirrel-cage motor.

By this arrangement the motor has two synchronous speeds with but one rotor winding, the connections

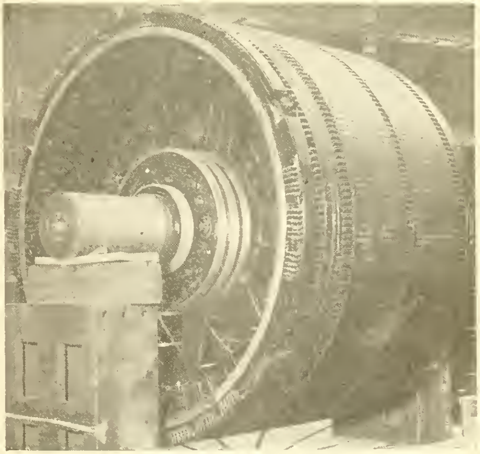


FIG. 9—ROTOR COMPLETELY WOUND AND CONNECTED

of which are not changed in any manner when going from one speed to the other. In arranging the motor windings to have the short-circuited rotor characteristics at 36 poles and to perform all starting and reversal at 24 poles, the advantage is gained that the propellers

can be brought from standstill up to full power quickly in either direction, without making any change in the motor connections.

The special connectors *B* described above are arranged symmetrically in six groups for the entire winding and are held down on a supporting ring by means

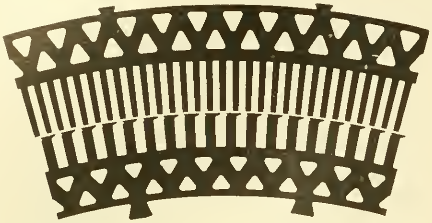


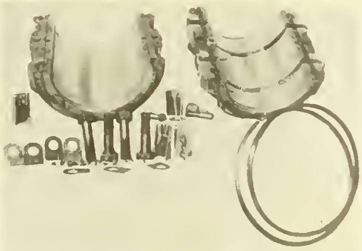
FIG. 10—VIEW OF STATOR AND ROTOR LAMINATIONS
Showing punched holes which form the air ducts for ventilating the cores.

of brass plates and bolts in a substantial manner. A close-up view of one such group on the finished rotor is shown in Fig. 8 and a view of the complete rotor is shown in Fig. 9. The rotor insulation is of the same general character as described for the stator.

The shaft is made of nickel steel with coupling flange forged integral. The shaft is hollow, having a nine inch diameter hole in the center throughout the length in order to reduce the weight and to permit thorough inspection of the material.

COLLECTOR AND BRUSH RIGGING

The three collector rings are made of brass and are assembled on a cast steel hub which is pressed on and



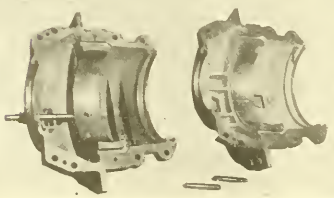


FIG. 11—MAIN MOTOR BEARING SHELL AND DETAILS
FIG. 12—INSIDE VIEW OF MAIN MOTOR BEARING HOUSING

keyed to the shaft. Each ring is cast solid, with four inwardly projecting arms and bolted to the hub with heavy bolts. The rings are well insulated from each other and from the hub by bakelite micarta washers, and as an additional precaution the arms of the rings are covered with treated cloth tape. The whole is then given several dippings in black asphaltum enamel and baked in a heater after each treatment. The brush rigging is assembled on a suitable casting and is securely bolted to the forward bracket.

VENTILATION

The motor is arranged with forced draft ventilation under normal conditions of operation. Two adjustable speed motor-driven exhaust fans are mounted on top of a sheet steel casing, which encloses the motor frame and serves to confine the cooling air. In addition the rotors themselves are provided with blowers so that the motors can operate at full power for short periods of time in case of failure of the exhaust fans, from any cause. The cooling air is taken from the

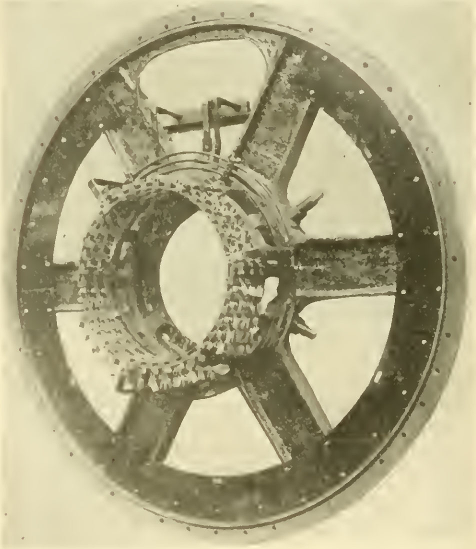


FIG. 13—BRUSH RIGGING MOUNTED ON MAIN MOTOR BEARING BRACKET

atmosphere at the main deck through ventilating trunks down to the motor room, drawn into the motor through openings between the arms in the bearing brackets to the coil ends, thence from both sides through axial ducts in the stator and rotor cores formed by punched holes in the laminations, Fig. 10. These axial ducts lead into one radial duct located centrally in the cores. This duct opens into the chamber confined by the sheet metal casing around the frame, whence the air is drawn up through the fans and then up through exhaust trunks to the deck. By this system of axial ventilation, the cooling air is brought in close contact with the parts of the machine where the heat is generated, the heat is conducted longitudinally through the core laminations and the paths of the heat flow are short, making this a very effective method of ventilation.

BEARINGS

The motor bearings are designed to carry the weight only of the rotor, the end thrust from the propellers being taken up by separate thrust bearings located directly aft of the motor rooms. The bearings are of the spherical seat, self-aligning type and are made of cast steel, babbitt lined, split through the horizontal diameter and so designed that the top half may be removed for examination of the journal without disturbing the lower half. Provision is made for adjusting the position of the bearings radially for the purpose of lining up and centering the rotor. The bearings are carried in cast steel housings, also split through the horizontal diameter, and these housings are secured to heavy cast steel brackets, made in one piece, rabbeted and bolted to the stator frame, the whole making a very rigid and substantial construction.

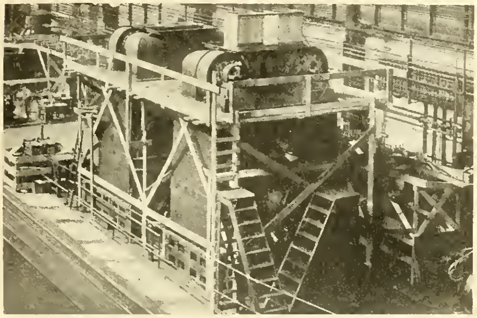


FIG. 14—TWO MAIN PROPELLING MOTORS COUPLED TOGETHER FOR LOAD TEST

One machine operating as motor and driving the other machine operated as an induction generator.

Under ordinary conditions of operation, lubrication of the bearings is supplied from the ship's oil pressure system. As a reserve provision, the bearings are also equipped with oil rings so that in case of failure of the oil supply the bearings are designed to operate indefinitely at full speed without overheating. Each housing is fitted with a thermometer and with an illuminated sight flow indicator in the oil drain. Particular care is also taken by means of oil guards to prevent oil from passing out of the bearing housings into the motor.

TESTS

The motors were tested at the factory to determine the actual performance characteristics, air delivery and temperature rise, and the motor performance at various speeds, based on these tests, is given in Table I.

For a load test, the shafts of two of the motors were rigidly coupled together, as shown in Fig. 14, one to operate as a motor, driving the other as an induction generator. The machine operating as a motor was supplied with power from a turbo-alternator, while the machine operating as an induction generator was excited from another turbo-alternator and delivered its power into the shop feeder system. By this method load tests were run which closely approximated the full power operation of the motors and the temperatures obtained were well within the safe limits for the class of insulation employed.

TABLE I—MOTOR PERFORMANCE

Knots per Hour	R. P. M.	Hp per Motor	No. of Poles	Approx. Cycles	Volts	Eff.	P-F.
21.8	180	8375	24	36.6	3460	94.6	84
21	170	7000	24	34.6	3270	94.8	83.4
19	151.5	4625	24	30.7	2900	94.5	80
16.7	132	3000	24	26.7	2520	94.3	74.5
15	118	2125	24	23.8	2250	93.5	68.6
15	118	2125	36	36.2	3250	91.6	71
10	77.8	600	36	23.8	1400	88.8	72

While making these load tests, an interesting opportunity presented itself for making a check test on the method employed in computing the efficiency of the motor. The efficiencies in the tabulation above are calculated on the basis of the separate losses being determined in the usual manner. When the load tests were made a set of kilowatt input-output readings were taken, showing an over-all efficiency of the two machines which checked to approximately one-quarter of one percent of the efficiency as calculated from the separate losses. This close agreement is gratifying since it rarely happens that load tests can be conducted on such large machines. Knowing the motor efficiency to within such close limits, the power consumption of the propellers under varying conditions can be determined with ease and accuracy, enabling a close analysis to be made of the whole problem of ship propulsion. This of itself is an important argument in favor of electric drive.

The Control Room Circuit Breaker Equipment of the U. S. S. Tennessee

E. K. READ
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THE circuit breaker equipment on electrically propelled battleships must be as reliable as the generators and motors themselves. Every detail must therefore be carefully considered, to be sure that nothing will fail and thus render any propelling unit inoperative. The circuit breakers are the means by which the flexibility of operation is secured and this advantage of the electric drive is lost if the circuit breakers are not at all times in good operating condition.

The operating conditions on the *Tennessee* are widely different from the usual commercial practice in that the total output of the generators is used by one set of motors, the generators being controlled to suit the load on the motors. To prevent damage to the machinery and also to prevent improper operation, causing delays, the generator and motor control equipment is interlocked so that improper operation is impossible.

An outstanding feature of the control is the requirement that the governor of the turbine be set for slow speed before the field of the main generator can be opened, and further that the field shall be opened before the power circuits can be opened or closed. The opening of the field contactor before operating any of the oil circuit breakers reduces the current broken in switching to a minimum, but the consideration of absolute reliability requires that the oil circuit breakers be capable of interrupting the generator current under any conditions the operator may impose on them. The generators, however, are never operated in parallel and the circuit breakers never open automatically.

This reducing of the power is required in order that the load imposed on the generators by the motors, when changing control set ups during maneuvering, may not be greater than should be placed on the turbogenerators. The operation of the circuit breakers after the power has been reduced also reduces the wear on the contacts from arcing and the burning and carbonization of the oil.

The castings are made of steel in preference to cast iron, where subject to any strains, because it is stronger, resulting in a lower weight. The apparatus must not be subject to the corrosive effect of moisture laden salt air, which requires that all parts must be made from nonferrous material or else protected with a rust preventive coating. All large shafts are made of cold rolled steel and thoroughly sherardized. All bearings for steel shafts are made with brass liners and provided with convenient oil holes. All small pins are made from phosphor bronze. All cotter pins, bolts, nuts and washers are sherardized.

CIRCUIT BREAKERS

The circuit breakers are mounted on 21 inch centers in a steel structure with steel barriers between adjacent breakers. Removable ebony asbestos doors cover each end of each cell. A working aisle of 30 inches is provided between rows of circuit breakers for use in inspection and maintenance, as shown in Fig. 1.

FIG. 1—AISLE BETWEEN ROWS OF CIRCUIT BREAKERS WITH TANK LIFTER IN USE

The oil circuit breakers included in this equipment are all single throw, and rated at 40 cycles, 3500 volts, as follows:—

Twelve 1600 ampere, two pole circuit breakers with three pole disconnecting devices for the generators and for motor reversing.

Two 800 ampere, three pole circuit breakers with three-pole disconnecting devices for motor ties.

Four 1600 ampere, three pole circuit breakers for the 24 pole connection.

Four 800 ampere, three pole circuit breakers for the 36 pole conection.

Four 2000 ampere, two pole circuit breakers for short-circuiting the motor secondaries.

The circuit breakers are made oil tight so that the rolling and pitching of the ship will not spill the oil, and are proportioned so that a proper head of oil is insured over the contacts under all conditions.

The circuit breaker used in short-circuiting the motor secondary is shown in Fig. 2. This picture

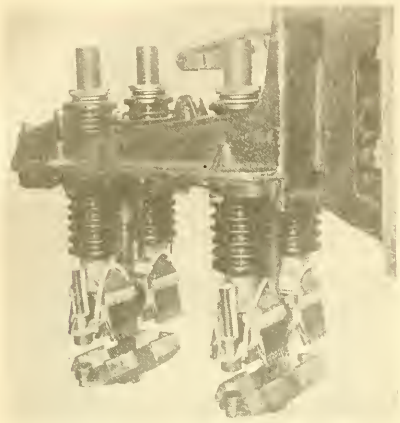

FIG. 2—2000 AMPERE, TWO POLE CIRCUIT BREAKER FOR SHORT-CIRCUITING MOTOR SECONDARY

gives a good view of the substantial construction of the circuit breaker. All of the castings are of steel or bronze with the exception of those carrying current which are copper. The wedge shaped moving contact with the renewable arcing screw are clearly shown. Two sets of fingers are used on this circuit breaker to keep down the length of the moving contact.

The circuit breaker is held closed by the toggle of the operating mechanism being forced over center, the operating lever being latched in the closed position as double security. Thus any failure in the connecting linkage or of the lever latch will not allow the circuit breaker to drop open.

Stationary Contacts—Fig. 3 shows the construction of the stationary contacts of the circuit breakers. The insulator is of molded bakelite which cannot be fractured by shocks from gunfire or other causes. The creepage distance over the surface is somewhat greater than in ordinary commercial practice because of the salt moisture conditions. The accuracy of the molding of this material made possible a clamp, which is machined where it fits the insulator and where it bolts up against a machined face on the circuit breaker frame, making the lining up of the contacts very simple. The large arcing contact is clearly shown, together with the twin shunts for keeping the current from the plunger guides during the opening period in the operation of the circuit breakers. A strong compression spring is used on the arcing contact, to insure that it follows the arcing screw down as the circuit breaker opens.

The forged copper fingers are carried on the end of a flexible copper leaf shunt backed up by a pair of strong springs which insure an even pressure on each finger. The springs are under considerable initial tension when the moving contact first engages the fingers, so that there is no possibility of the contacts chattering during the closing and opening operation.

Finger contacts were adopted for this insulation because the equipment must be easy to operate. Finger contacts make a circuit breaker easier to operate than any other type of contact because the contact pressure is lower and because the vertical component of the contact pressure is only about a third of the normal pressure. The major portion of the effort required to operate a circuit breaker is used in overcoming the sliding friction of the contacts which is low because the pressure is low. Finger contacts are also desirable because, since they are individually small, uniform contact is obtained over the total area of the contact surface.

Disconnecting Device—The details of the two-pole 1600 ampere circuit breakers with three-pole disconnecting devices are shown, with the disconnecting device closed and the tank on, in Fig. 4, and with the disconnecting device open and the tank off in Fig. 5. The disconnecting device consists of a set of contacts carried on a rigid base supported in the main steel structure. The contacts are located on the base with a spacing that corresponds to the spacing of the contacts on the circuit breakers. They are duplicates of the circuit breaker stationary contacts with the exception that there are no arcing contacts. Arcing contacts are not needed because the disconnecting device is interlocked to prevent its being opened or closed unless the circuit breaker is open. The fingers on the bottom

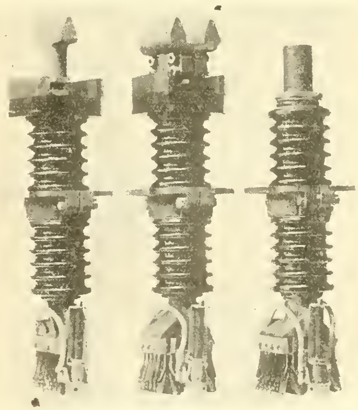

FIG. 3—CIRCUIT BREAKER STATIONARY CONTACTS

of the contacts engage wedge shaped terminals on the circuit breaker studs when the circuit breaker is pushed up under it.

The circuit breaker is carried on a cradle which slides up and down on two vertical parallel rods which

are supported from the steel structure by steel castings. The cradle is raised by means of a toggle device which goes over center against a stop in the closed position.

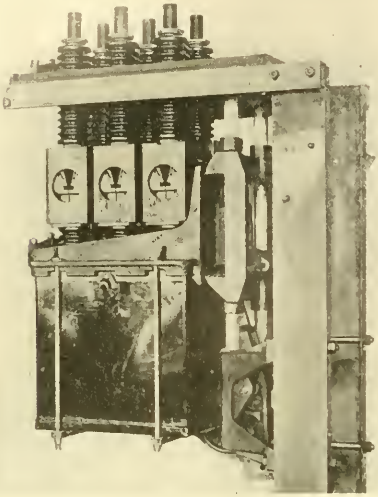

FIG. 4—CIRCUIT BREAKER WITH TANK ON AND DISCONNECTING SWITCH CLOSED

This provides ease of closing, definite location in the closed position and assurance that it will stay in the closed position in spite of any shocks. The toggle is

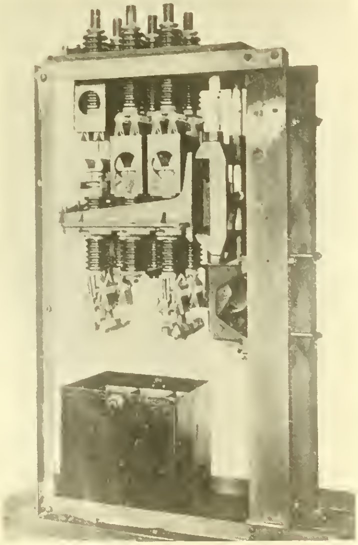

FIG. 5—TWO-POLE CIRCUIT BREAKER WITH TANK OFF AND DISCONNECTING SWITCH OPEN

restrained, when in the closed position, by a wing nut as an additional safe guard. Since the stationary contacts of the disconnecting device are directly over the circuit breaker studs, the raising of the circuit breaker provides a straight line path from the bus-bars down through the circuit breaker and up again to the bus-bars on the other side. The contacts are surrounded by micarta tubes to provide additional insulation between studs in the closed position. The hole in the tube is provided for ventilation.

STRUCTURE ASSEMBLY

Fig. 6 shows a front view of the structure, taken while the apparatus was on the shop assembly floor, with the ebony asbestos doors off, showing the operating end of the circuit breakers. The circuit breaker at the left is shown open with the removable handle, one of which is placed in each cell so as to be always available, inserted ready to lower the circuit breaker out of the disconnecting device. The crescent shaped

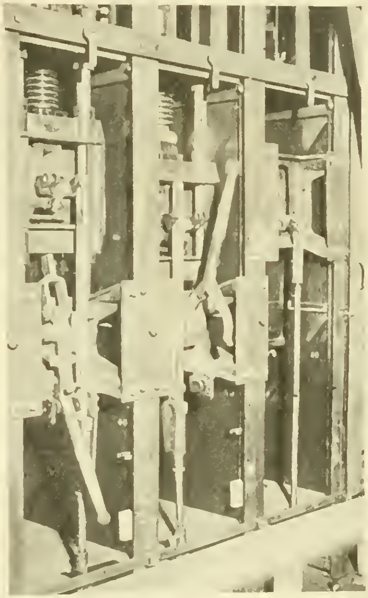

FIG. 6—CIRCUIT BREAKER STRUCTURE WITH DOORS OFF

cam on the side of the vertical operating bar prevents the lowering of the circuit breaker unless the circuit breaker is first opened. The second circuit breaker has been lowered. The curved guard on the raising and lowering toggle lever has moved around the cam on the bar so as to prevent the closing of the circuit breaker. The steel plate extending down along side of the operating bar prevents the removal of the pin connecting the bar to the rod which connects to the operating lever. When the circuit breaker is open the pin is opposite the hole in the guard and can be removed. The arm on the toggle lever prevents the removal of the tank unless the circuit breaker is lowered so that the disconnecting device is open. The circuit breaker on the right does not have a disconnect-

ing device and is therefore mounted rigidly in the steel structure.

The confined space in which the circuit breakers are mounted, together with the rigidity of the tank supports and the weight of the tank when filled with oil, requires a truck type of tank lifter. This is shown in use in Fig. 1. A cradle which carries the tank is

FIG. 7—MAIN GENERATOR FIELD CONTROL EQUIPMENT
Consisting of field contactor and booster field rheostat.

raised and lowered by means of the long screw shown in front. The removable handle furnishes an easy means for rotating this screw. One of the three wheels is shown at the front just under the screw. The tank lifter is made sufficiently strong that it can be used in mounting or removing a complete circuit breaker.

FIELD CONTACTOR

Since the field contactor must open and close every time a switching operation is made the duty on it is very severe. In case the booster set is not running, the field contactor may have to interrupt the full field current of the main generator. It is capable of opening the maximum field current several thousand times without requiring attention or renewal of the arcing contacts.

The ruggedness of the field contactor is evident from Fig. 7. It is built on the lines of standard starting contactor practice, with rolling contacts which provide a main copper to copper circuit, and with the final break taking place between a carbon arcing contact and the curled end of the moving contact. A strong blowout coil and arc chute with arc splitters is provided on the upper or main contact. The lower or field discharge contact engages before the upper contact is broken. The contactor is closed by a spring which is carried across center by the forward motion of the operating lever and is retained by a latch in that position while the booster field rheostat shown at the right is adjusted by the backward and forward mo-

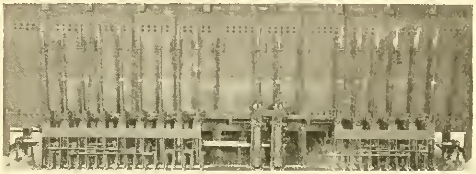

FIG. 8—SHOP ASSEMBLY OF OPERATING LEVERS

tion of the operating lever. Moving the lever to the extreme backward position disengages the latch and the operating spring, now on the other side of center, and opens the contactor with a snap.

Since it was desired to keep the equipment as simple as possible, the field contactor was made manually operated. The latching of the contactor closed permitted the use of the same operating lever for varying the booster field rheostat, as shown at the right in Fig. 7. It is connected to the operating rod by a rack and pinion. The latch on the field operating lever has 35 teeth which permits close adjustment of the booster rheostat and prevents the adjustment from changing when once set.

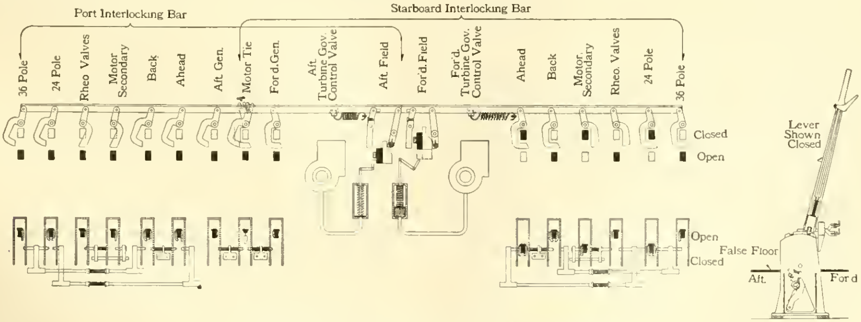

FIG. 9—SCHEMATIC DIAGRAM OF LEVER INTERLOCKS

OPERATING LEVERS

The operating levers for control of the propulsion machinery are grouped together as shown in Fig. 8. This places the entire operation immediately under the observation of the officer on watch in the control room. This compactness makes the interlocking more simple

and positive, because the interlocking members can be made short and rigid.

The operating levers are of the type commonly used in railway signal interlocking plants. The handles are at a convenient height above the false floor, with the operating rods, shafts and bell cranks on the deck below the floor. The effort required to move the lever from one position to the other is well within the strength of the average man, using one hand. The handle travels a distance of 26 inches, the lever arms being in the ratio of 4 to 1. The levers are provided with latches to hold them in their extreme positions. Failure of this latch does not permit the circuit breakers to move, as previously explained. The levers and interlocks are made strong enough to withstand the maximum efforts of the operator if he attempts an improper operation.

FIG. 10—PORT OPERATING LEVER INTERLOCKS

A very complete set of interlocks is provided, as shown schematically in Fig. 9 there being two tiers, one of the shuttle pin type below the fulcrum, and the other consisting of hook and stub interlocks above the fulcrum. Fig. 10 is a view looking down on the upper row of interlocks on the port side. The hydraulic governor control valve is shown at the right. The hook interlocks, which prevent the opening or closing of a lever when the field contactor is closed, are clearly shown. The second lever from the right is the tie breaker lever with a pair of hooks, one connected to each of the two interlock bars.

The following interlocks are provided:—

a—The field contactor is prevented from opening, unless the steam wheel has been placed at the slow speed setting, by a piston in a cylinder connected to the hydraulic control of the governor. Raising of the piston pushes a dog into the path of the lever and prevents the final movement necessary to disengage the field contactor latch. This lock, in connection with (d), insures that the motors will not be reversed at high turbine speed, with an excessive power demand from the system.

b—The field contactor lever cannot be closed unless the liquid rheostat valve lever and the motor secondary short-circuiting breakers are in the open position, clear of the stubbing interlock, allowing the interlock bar to move transversely and move the interlock at the left of the field lever out from in front of the field lever. This prevents energizing a motor unless maximum resistance is inserted in the motor secondary.

c—A pivoted cam on the tie breaker lever prevents the closing of the tie breaker lever if both generator breaker levers are closed, or of one generator breaker lever if the other generator breaker lever and the tie breaker lever are closed. This cam engages the shuttle interlock bars in the lower tier between the generator levers and the tie breaker lever. This prevents paralleling the generators.

d—The closing of the field contactor lever drives the interlock bar transversely and causes the hook interlocks to prevent movement of any of the levers except those controlling the rheostat valves and motor secondary short-circuiting breakers. The interlock bar is prevented from moving from the locking position, while the booster field rheostat is being adjusted, by a dog not shown in Fig. 9, which is disengaged by the last movement of the lever that also trips the field contactor. This prevents operating the circuit breakers, except when the generators are de-energized. This not only accomplishes the purpose given under (*a*), but also reduces the wear of the arcing tips and the rate of carbonization of the oil, as the currents have fallen to low values before the breakers are opened.

e—The movement of the interlock bar by the field lever moves the stubbing interlocks from in front of the rheostat valve and motor secondary levers so they can be closed, except as covered in (*g*). There is no restriction upon the opening of the two levers last mentioned.

f—The closing of the tie breaker lever mechanically connects the port and starboard interlock bars by connecting together the two hook interlocks, each of which is connected to a different bar. This is clearly shown in Figs. 9. and 10. This provides for locking the breaker levers of all four motors by means of either generator field lever, when the motors are operating from one generator.

g—The lever controlling the motor short-circuiting breakers is prevented from closing until after the lever controlling the rheostat valves has been closed, which pushes the square ended lower interlock out of its path. This prevents short-circuiting the motors, without first allowing the rheostat liquid level to be raised. The breaker lever is not closed until after the liquid reaches its maximum level as observed from the gauge glass on the liquid rheostat.

h—The following pairs of levers are prevented from being in the closed position at the same time by straight pin type interlocks in the lower tier.

Ahead ——— Back
24 Pole ——— 36 Pole
36 pole ——— Back

The 36 pole connection is for economical cruising purposes only and there is no necessity for backing on this connection.

i—The ahead lever is prevented from closing until after the 24 pole lever has been thrown, by a square end pin interlock in the lower tier, which is moved out of the way by the closing of the 24 pole lever. This lock is a reminder that the motors must be started on the 24 pole connection.

j—A circuit breaker cannot be lowered out of the disconnecting devices unless the circuit breaker is open. The circuit breaker cannot be disconnected from the operating rod unless it is open. If the circuit breaker is lowered, the operating lever cannot be moved unless disconnected from the circuit breaker. The circuit breaker tank cannot be removed unless the circuit breaker is lowered out of the disconnecting device.

The Control Equipment for the Propelling Machinery of the U. S. S. Tennessee

M. CORNELIUS
Switchboard Engineering Dept.,
Westinghouse Electric & Mfg. Company

APPARATUS for battleship service must be rugged and extremely reliable. In addition to withstanding ordinary shipboard conditions, it must be unaffected by severe shocks such as the ship may experience from her own gunfire or from external sources. The insulators for the high voltage apparatus are therefore made of molded bakelite or of pressed micarta tubes. Ebony asbestos wood is used for switchboard panels and controllers. Cast grid resistors are not permitted except where they are very heavy, and light grids are of expanded alloy sheets. Alloy ribbon is also used for resistors. Wire resistors are wound on steel tubes insulated with sheet asbestos. The circuit breakers are equipped with shockproof latches and overload trips have time element dash pots as an extra precaution against accidental tripping.

The possible deflection of decks and bulkheads must be considered in designing structures. A structure having uprights extending to an upper deck is not braced rigidly and if clips are used they are slotted for the bolts so that a deck deflection would not cause the uprights to buckle. Structures are located at least six inches away from bulkheads for the same reason.

Mechanical interlocks are installed where mistakes in operation would damage machinery or cause personal injury. These interlocks also prevent delays in operation by insuring that the correct sequence is followed. Electrical interlocks are used only where mechanical interlocks are not feasible, or where the two pieces of apparatus to be interlocked are widely separated.

Apparatus in the engine rooms or cables passing through them must be capable of operating in room temperatures which average 110 derees F. The control room and motor rooms are comparatively cool, the latter especially so because of the large volume of outside air supplied to the propelling motors.

THE CONTROL ROOM

The control equipment for the main turbogenerators and for the propelling motors is located in a control room separated from the machinery rooms by watertight bulkheads. The switchboards for the direct-current generators are located in the engine rooms and the controllers for the motor driven pumps and blowers are located close to their respective motors.

The control room equipment consists of the following apparatus:—

a—Contactors with discharge resistors and booster field rheostats for controlling the excitation of the alternating-current generators.

b—Oil circuit breakers for the generator and motor circuits. These provide for operating the four motors from one or two generators, for reversing the direction of motor rotation, for operating the motors on their low-speed or high speed pole connections and for short-circuiting the motor-secondary leads.

c—Liquid rheostats for starting the propelling motors, together with controllers for the electrolyte circulating pump motors.

d—Operating levers for the field contactors, oil circuit breakers and liquid rheostat valves.

e—Main turbine control equipment, consisting of hydraulic control valves for regulating speed, controllers for the motor driven power limiting devices and emergency pulls for the throttles.

f—An instrument board, supported from the circuit breaker structure, containing gages, electrical instruments, lamp indicators, rudder indicator, shaft revolution counter, turbine and shaft speed indicators, machine temperature indicators and various direct-current power switches.

g—Communication equipment, consisting of voice tubes, telegraphs, telephones, gongs, telautograph, revolution indicators, etc. for receiving and transmitting orders.

h—A gage and instrument board containing fuel oil, feed water and steam gages, oil burner control telegraphs, oil pressure indicators, smoke indicators, etc., at the water tender's station.

The propelling machinery is in no way controlled from the bridge, but all operations necessary to the starting, stopping, reversing and speed control of the propellers are done in the control room on orders received over engine-order telegraphs and by telephone from the bridge. Operation is in charge of an officer stationed in the control room. The fire rooms, engine rooms, motor rooms and shaft alleys receive their orders from the control room.

THE DIRECT-CURRENT POWER SYSTEM

The connections of the principal alternating and direct-current circuits are shown in Fig. 1. Each engine room switchboard controls three 300 kw 120 /240 volt, three-wire direct-current generators, a 35 hp booster set for the alternating-current generator field voltage variation, feeders to the motor controllers in the pump room, excitation and auxiliary power feeders to the control room, a feeder to the opposite engine room, and feeders to the corresponding distribution board. Each switchboard has a set of three-wire light and power bus-bars and two sets of two-wire propulsion auxiliary bus-bars. Fig. 2 shows the switchboard in the after engine room.

The light and power bus-bars of the engine-room boards connect directly through knife switches and cables to the corresponding distribution board. All of the ship's light and power circuits are controlled from these two distribution boards. These boards are interconnected so that any part of the ship can be supplied by power from either engine room, although the two engine rooms cannot be operated in parallel.

Three-wire direct-current power can be supplied to the ship, when docked, from a shore system, through terminal boxes on deck and thence through cables to a generator panel of the after engine room board. The switches on this panel are double throw, the upper throw connecting the light and power bus-bars and the main auxililiary bus-bars to the generator and the lower throw connecting them to shore power. Shore power can thus be distributed to any part of the ship.

One of the three 300 kw turbogenerators in each engine room—the non-condensing unit—is considered as belonging to the propelling equipment and the other two are considered as belonging to the ship's light and power plant. However, all three units can be used interchangeably for either service.

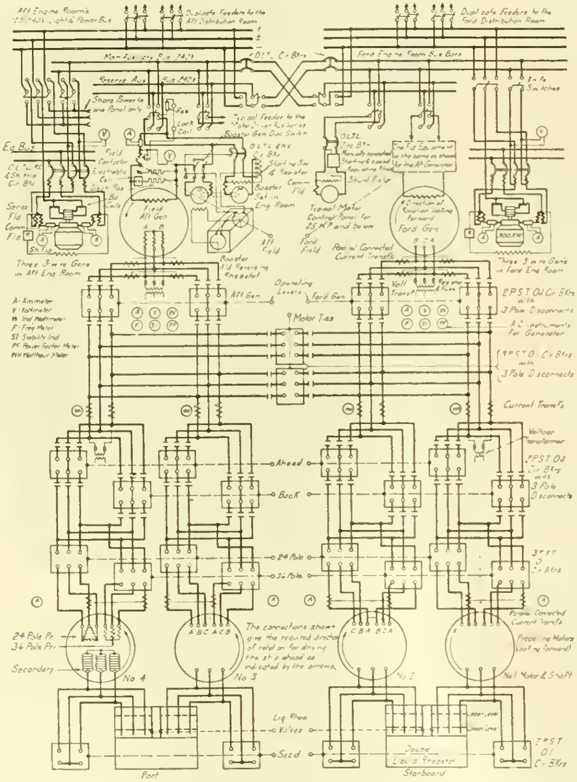

FIG. 1—THE PRINCIPAL ALTERNATING AND DIRECT-CURRENT CIRCUITS

CONTROL OF THE DIRECT-CURRENT TURBOGENERATORS

The overspeed mechanism of the turbine is equipped with an auxiliary switch which is connected in the shunt trip circuit of the generator breaker, so that the circuit breaker opens automatically when the throttle has been tripped, either due to overspeed or by hand through the wire pull located at the switchboard.

The generators are protected by two two-pole circuit breakers having a common tripping mechanism. The two equalizer poles are of approximately one-half the current capacity of the two main poles. Each equalizer and main pole has an overload time limit trip and in addition, one main pole has a shunt trip and the oth- main pole, a reverse current trip. Each main pole has an extra stud between the overload coil and the brush for the connections to the bus-bars which supply the 240 volt propulsion auxiliary load. This load, which includes the main generator field excitation, passes through the overload coils but is not interrupted when the circuit breaker opens.

The upper studs of the main poles of the circuit breakers connect through a switch to the ship's light and power bus-bars, which in turn connect to the distribution boards. The generators are paralleled by closing the equalizer poles of the circuit breaker, no switches being provided in the equalizer circuits. A mechanical interlock is provided on the circuit breaker between the closing arm of the equalizer poles and that of the main poles, so that the equalizer poles must be closed first.

Two knife switches are provided on each generator panel for connecting the generator to the three-wire light and power bus-bars and to the two-wire main auxiliary bus-bars. A generator can thus supply both sets of bus-bars simultaneously, if desired.

All three generators can be paralleled on the light and power bus-bars. They can also be paralleled on the main auxiliary bus-bars by disengaging mechanical interlocks between the switches connected to these bus-bars. These interlocks are self re-setting after a switch has been opened and are installed as a reminder that two generators are not to operate in parallel on the auxiliary bus-bars except for the time required to transfer the load from one generator to the other.

The second set of two wire bus-bars provided on the engine room switchboard is energized at all times as a reserve source of supply for the propulsion auxiliary load, and has a separate voltmeter. These bus-bars can be connected to two sources of supply by means of a double-throw switch. When the ship is cruising, one engine room will normally be shut down and the switch will be thrown to the light and power busbars of the active engine room. When the second engine room is standing by ready for service, or if the ship is steaming at high speed with both engine rooms in operation, the switch will be thrown to the main auxiliary bus feeder from the other engine room.

Each main auxiliary bus feeder to the opposite engine room has an ammeter and an overload time limit circuit breaker to clear the line automatically in

case of trouble in the opposite engine room. The supply from the reserve auxiliary bus is therefore subject to automatic interruption.

Each generator has a voltmeter, two ammeters connected to ammeter shunts located in the armature leads at the generator and a three-wire watthour meter connected to shunts located behind the switchboard.

The field rheostat is supported from the rear framework of the switchboard and is operated by shafts and bevel gears from a hand wheel on the front of the board. The rheostat has a large number of resistance steps and a wide range of voltage can be obtained in case it is necessary to shut down the booster set and excite the alternating-current generator field directly from one of the 300 kw generators.

FEEDERS TO THE MOTOR DRIVEN PROPULSION AUXILIARIES

Double-throw knife switches are provided on the engine room boards for connecting the feeders for the propulsion auxiliaries to either of the two sets of auxiliary bus-bars. All of these switches except the switch for the alternating-current generator field excitation are capable of being thrown from one bus to the other under load, so that the auxiliaries will not be shut down if the emergency requires that the transfer be made. The larger switches have special blades and auxiliary breaks to reduce the time of throwing over and to assist in breaking the circuit.

There are six feeders on each board for the motors which drive pumps for the condensers and for the forced lubrication system. The feeder to the control room is fused, and a red lamp is used to give a prominent indication of the condition of the fuses. Each of the above feeders have ammeters in circuit. Five switches are installed for engine room ventilating motors and one for an oil purifier motor.

Each motor driven auxiliary has its controller mounted within easy reach of the motor. All controllers are manually operated and have overload and no voltage protection.

CONTROL OF THE BOOSTER SET

The engine room switchboard contains the necessary control equipment for the booster motor-generator set which is used for varying the voltage across the main generator field. No alternating-current generator field rheostat is used, and the booster set adds to or subtracts from the auxiliary bus voltage of 240 according to the excitation demands.

A double-throw switch is provided for connecting the alternating-current generator field circuit and the booster set circuit to either set of auxiliary bus-bars. The switch has a solenoid operated latch on each throw, which prevents opening the switch unless the alternating-current generator field circuit is open at the field contactor in the control room.

The booster set runs at constant speed, and its motor takes power from the busses when the set is boosting and returns power to the busses when the set is bucking. The voltage of the booster generator is varied in either direction from zero by means of a reversing field rheostat located in the control room. The rheostat has a single resistance connected across the 240 volt auxiliary bus and the various resistance taps are connected in a special manner to two face plates. The voltage across the booster generator field is practically zero when the face plate arms are vertically downward. When they move in one direction from this neutral point, voltage of one polarity is gradually increased across the booster generator field and when they move in the opposite direction from neutral, the field voltage is gradually increased in the opposite direction.

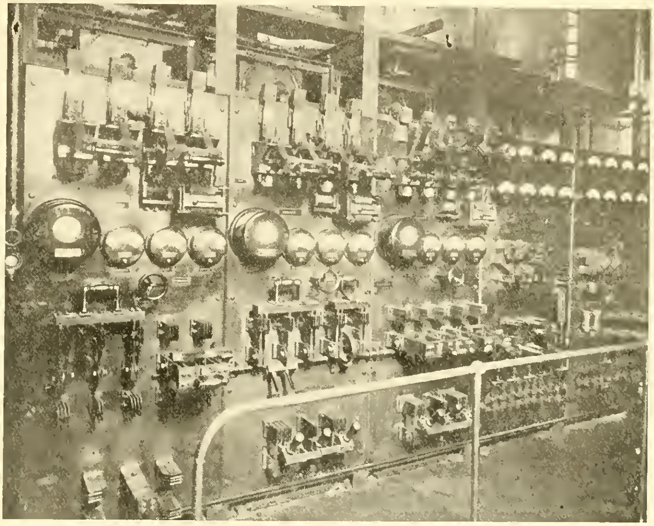

FIG. 2—THE DIRECT-CURRENT SWITCHBOARD IN THE AFTER ENGINE ROOM

The booster motor is protected by a two-pole circuit breaker having overload time limit and no-voltage trip. The opening of this breaker also opens the circuit to the booster field rheostat, thus de-energizing the booster generator field. The motor is started by means of a single-pole, four-point starting knife switch and a resistance. The booster generator circuit is always open until after the booster set has been started.

A two-pole double-throw transfer switch, which does not open the circuit during transfer, is provided

for disconnecting the booster generator or for placing it into service without the necessity of interrupting the main generator field circuit. The switch has an auxiliary pole which opens the circuit to the booster field rheostat, so that the booster generator cannot be short-circuited with its field energized in case the switch is thrown before tripping the motor circuit breaker. A field voltmeter and field ammeter for the alternating-current generator and a double reading ammeter for the booster motor are installed on each engine room board.

DISCONNECTING A BOOSTER SET WITHOUT INTERRUPTING THE ALTERNATING-CURRENT GENERATOR FIELD CIRCUIT

If trouble develops in the booster equipment and it becomes necessary to excite the main generator directly from one of the 300 kw generators, the following operations are necessary:—

a—Trip the booster motor circuit breaker. The main generator field voltage becomes 240 after the set has stopped.
b—Pull the motor starting switch.
c—Throw the booster generator switch up, thus disconnecting the generator.
d—Throw the auxiliary motor and control room feeder switches to the reserve auxiliary bus one by one, until only the main generator field circuit remains on the main auxiliary bus.
e—Vary the main auxiliary bus voltage by means of the 300 kw. generator field rheostat, as may be required by the control room.

Both booster sets could be inoperative and the ship could still steam at full speed, using one 300 kw generator in each engine room as exciters for their respective main generators. Both alternating-current generators can be excited from one 300 kw generator if the emergency should require it. In this case excitation for the main generators is taken from the main auxiliary bus of the room which furnishes the exciter and from the reserve auxiliary bus, through the tie line, of the opposite engine room. A temporary interruption of the driving power is required to set up the exciting circuits according to this latter scheme.

OTHER FEATURES ON THE ENGINE ROOM BOARDS

Each board has a calibrating voltmeter which can be connected in parallel with the generator and bus voltmeters by means of a multicircuit switch. The operator can compare the voltages of the running and incoming machines on this voltmeter when paralleling generators. Each board also has a double reading ground detector voltmeter with a multi-circuit switch so that any bus can be connected to ground through the meter. The voltage of the booster generator can also be read on this meter.

All ammeter and watthour meter shunts have removable strips in series with them to facilitate inserting a portable shunt for testing purposes. Totalizing ammeters are installed in each main and reserve auxiliary bus.

DIRECT-CURRENT CIRCUITS IN THE CONTROL ROOM

The control room feeders from the 240 volt auxiliary bus-bars in each engine room come to switch panels forming a part of the main instrument board in the control room. Eleven two-pole, double-throw switches are installed for distributing power from either engine room to the controllers for the motor room blowers, for the liquid rheostat pump motors and for the oil drainage pump motors. Two feeders lead into each motor room for the blower motors and heaters so that either blower can be stopped from the control room if desired, by pulling the feeder switch. A red lamp located at each switch is connected across the armature of the blower motor to indicate when the motor is in operation.

Two panels, one on each liquid rheostat, provide control for the electrolyte circulating pump motors and have switches and fuses for the control circuits to the turbine governor control valve vibrating motors and to the motors on the turbine power limiting devices. Each pump motor has two single-pole overload time limit circuit breakers with a common trip which also serve as a line switch. Two contactors which shunt a three-point resistor are provided for the automatic starting and no-voltage protection of the motors.

There are three sets of oil drainage pumps and motors under the control room, only two of which are connected in at any one time. The other set is held as a reserve in case of the failure of one pump. The control room board has a two-pole, single-throw switch and a red light for each motor and in addition a double-throw switch for transferring the control circuits from the two tank float switches to the two motors and pumps selected for operation. The red light is connected across the motor armature to show when the motor is operating. The motor controllers are of the automatic contactor type.

BLOWER MOTOR CONTROLLERS IN MOTOR ROOMS

A two-panel board is located near the two blowers on each main motor for controlling the adjustable speed blower motors and the main motor heaters. Each motor has two single-pole overload time limit circuit breakers having a common trip and a sliding arm starting and field regulating rheostat. A two-pole, single-throw fused switch on one panel controls the heater circuit of the propelling motor. Two bulkhead type lamps attached to the main motor and connected across the armatures of the blower motors indicate to a man on the lower grating of the motor room when the blower motors are in operation.

MAIN GENERATOR FIELD CONTROL EQUIPMENT

The field circuits of the alternating-current generator and of the booster generator are looped into the control room in order to provide manual operation of the field contactor and booster rheostat. The field contactor and booster rheostat are operated in common from one lever, the contactor closing on maximum field voltage at the extreme forward end of the lever travel and opening on minimum field voltage at the other extreme of the lever travel. This method of operation causes the field current to build up quickly.

The booster operates at maximum buck with the field contactor open. In closing the operating lever, the booster generator voltage changes from maximum buck through zero and to maximum boost, and the field contactor is closed just before the lever reaches the extreme forward end of its travel. The lever is then immediately brought back to the desired voltage position. The field contactor does not open until just before the lever reaches the off position, when the booster is again running at maximum buck.

The upper and lower contacts of the field contactor are temporarily bridged during the operation of opening or closing. The field discharge resistor is thus shunted across the field before the exciting circuit is opened, and is of low enough resistance to limit to a safe value the voltage induced upon the collapse of the field. The resistor is of ample capacity for several successive field interruptions, such as might occur in maneuvering.

A duplicate field discharge resistor is located in the engine room, and is connected in series with an electrolytic cell directly across the field terminals. This is installed as additional insurance against a breakdown of the field which might occur if the field discharge circuit in the control room should ever become impaired. The cell takes a slight charging current when the field is being excited. When the exciting circuit is interrupted, the cell breaks down upon the reversal of the polarity across its terminals and allows the discharge current to pass through and be absorbed in the resistor.

OIL CIRCUIT BREAKER EQUIPMENT

The alternating-current generator and motor circuits are controlled by manually operated oil circuit breakers which are capable of interrupting their rated currents at full voltage, but their operating levers are so interlocked with the field and steam control that they cannot normally be opened under full power. The steam supply to the turbine is partially cut off and the generator field circuit is opened before the breakers can be opened. The generators are never operated in parallel, so that the breakers never have more than the power of one generator behind them. The circuit breakers have no automatic features. The breakers are operated in pairs. There are two breakers in parallel for each generator circuit and for the tie circuit. The reversing, pole changing and secondary short-circuiting of the motors is done as if the two motors on one side of the ship were one unit.

The generator, tie and motor reversing breakers are equipped with self contained disconnecting devices so that any circuit breaker can be isolated and inspected with safety even though the ship is under way. Except for the tie breakers, which are three-pole, the breakers having disconnecting devices are two-pole and the third lead is isolated by opening the disconnects. This arrangement was adopted to reduce operating effort.

DISCONNECTING A PROPELLING MOTOR

A propelling motor can be completely isolated from the bus-bars in a few minutes time by lowering its ahead and astern circuit breakers, thus opening the disconnects, and by removing the pins which connect the breakers to the operating levers. If the outboard motors, for example, have been disconnected, operation can be resumed using the inboard motors, and the levers are manipulated exactly as they were before. The pole changing circuit breakers of the idle motors are not disconnected from their operating levers as these are dead when the disconnects of both reversers are open.

ARRANGEMENT OF CONTROLS

The general arrangement of the control room is shown in several illustrations in this issue. The operators face forward and have all levers, instruments, gauges and lamp indicators within close range, as shown in Fig. 3.

The oil circuit breakers for the generator, tie and motor primary circuits are mounted in cells in a steel structure in front of the operating space. The four motor secondary oil circuit breakers and the two double liquid rheostats are located behind the operating space, as shown in Fig. 4. The field contactors, discharge resistors and booster rheostats are mounted on the outboard motor room bulkheads. Fig. 5 shows a works assembly of the primary structure for one of the later ships having the same equipment.

All operations are done from the operating space except the opening of the disconnects and the removal of the pin to disengage a breaker from the lever mechanism. These two operations are done from the narrow aisles next to the forward bulkhead and under the instrument board. Tank removal and contact inspection is done from the center aisle of the primary structure. The cells have a removable door at each end for access to the breakers.

The bus-bars and connections above the circuit breakers are of bare copper straps fastened together with brass bolts, and are rigidly supported against distortion from any cause. The bus-bar supports have molded bakelite insulators with clamped fittings and a pair of steel angles, between which the bars are held by brass bolts. All high voltage bus-bars are enclosed with expanded metal screens to prevent accidental contact with live parts. The voltage transformers with their primary fuses and resistors are located above the center aisle of the primary structure and are made accessible by unbolting and dropping hinged steel doors. The controllers for the liquid rheostat pump motors are supported from the upper tanks of the rheostats.

OPERATING LEVERS

The operating levers are mechanically interlocked to insure the proper sequence of operation and are divided into three groups for operation and are manipu-

lated by three men under orders from the officer of the watch.

The central operator has control of the following:—

Two field levers.
Two wheel operated main turbine governor control valves.
Two governor stop motor reversing controllers, mounted on the control valves.
Two turbine throttle trips, mounted overhead.

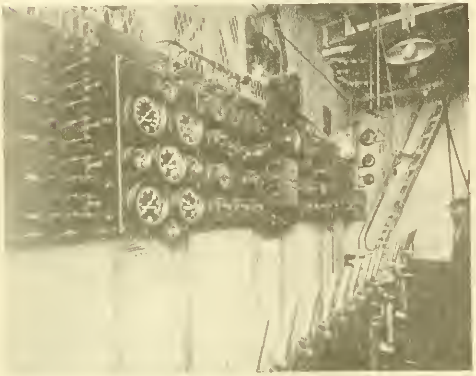

FIG. 3—CONTROL ROOM OPERATING LEVERS AND INSTRUMENT BOARD AS VIEWED FROM THE PORT SIDE

The operator on the port side has control of the following:

Two generator breaker levers.
One motor tie breaker lever.
Two motor reverser levers, Ahead and Back.
One liquid rheostat valve lever.
One motor secondary breaker lever.
Two pole changer levers, 24 pole and 36 pole.

The operator on the starboard side has control of six levers which correspond to the six end levers on the port side or the last four items listed.

The levers have distinctive coloring to make it easier to observe the set-up which an operator has made. The Ahead and Back levers are colored white and red respectively, to correspond with the engine order telegraph dials and are equipped with signal contacts which are so connected with the telegraphs that a buzzer is sounded if the operator throws a lever contrary to signal. The 36 pole levers are colored green to distinguish them from the adjacent 24 pole primary and secondary equipment levers which are black. The generator, tie and field levers are also painted black.

SEQUENCE OF LEVER OPERATIONS

The following are the lever operations for various running conditions. The turbogenerator is running at approximately 35 percent speed, and all levers are open and the speed wheel is on zero.

Condition 1:—Operating one generator with motors on the 24 pole connection.

A—To start:—

1—Close the tie circuit breaker lever.
2—Close the breaker lever of the generator in use. (Disconnects for idle generator circuit breaker open, unless it is desired to have generator standing by for immediate service in case of emergency.)
3—Close the 24 pole circuit breaker levers on both sides.
4—Close the ahead circuit breaker levers on both sides.
5—Close the field lever hard over and bring it back several notches immediately. The motors are now energized and will start to rotate.
6—Close the rheostat valve levers on both sides
7—When the liquid in the rheostats has reached its maximum level as observed from the gauge glasses, close the secondary short circuiting breaker levers on both sides.
8—Open the valve levers on both sides to drop the liquid level and prepare the rheostats for the next operation.
9—Adjust the turbine speed and generator excitation to the proper running values. Adjust the governor stop setting so as to prevent any sudden increase of load being taken by the turbine from any cause. The excitation must not be allowed to fall below a certain value for any given speed or the motors will fall out of step. Stable operating conditions are observed from the electrical instruments.

B—To stop:—

1—Set steam wheel for slow speed.
2—Open field lever.
3—Open the secondary short-circuiting levers on both sides.
4—Open ahead levers on both sides.

C—To back on one or both sides:—

1—Close the reversing levers according to signal, and proceed according to instructions under headings **1-A-5 to 1-A-9** above.

Condition 2:—Operating two generators with motors on the 24 pole connection.

This differs from Condition 1 in that both generator breaker levers are closed, the tie breaker lever is open, both steam wheels and both field levers are manipulated and the port and starboard field interlock bars operate independently.

Condition 3:—Operating one generator with motors on the 36 pole connection.

A—To start:—

1—Bring the motors up to speed on the 24 pole connection as per instructions for Condition 1. (Before changing over wait several minutes until the ship has picked up a speed ahead corresponding to the propeller revolutions, otherwise the motors will draw heavy currents and may fall out of step).
2—Set steam wheel for slow speed.
3—Open field lever.
4—Open the secondary short circuiting levers on both sides.
5—Open 24 pole levers on both sides.
6—Close 36 pole levers on both sides.
7—Close field lever.
8—Adjust speed.

B—To stop:—

1—Set steam wheel for slow speed.
2—Open field lever.
3—Open 36 pole levers on both sides.
4—Open ahead levers on both sides.
5—Close 24 pole levers on both sides
(Interlocks prevent backing on the 36 pole connection and the procedure in backing is the same as under Condition 1-C above.)

ALTERNATING-CURRENT GROUND DETECTOR SYSTEM

Each alternating-current generator circuit has connected to it three voltage transformers, duplicates of those used for operating the instruments, which are star connected with the neutral point grounded on the high-voltage side, and delta connected with a voltage relay inside the delta on the low-voltage side. Each relay actuates an auxiliary relay, and these in turn complete a buzzer circuit to warn the operator of a ground. The contacts of the auxiliary relay remain

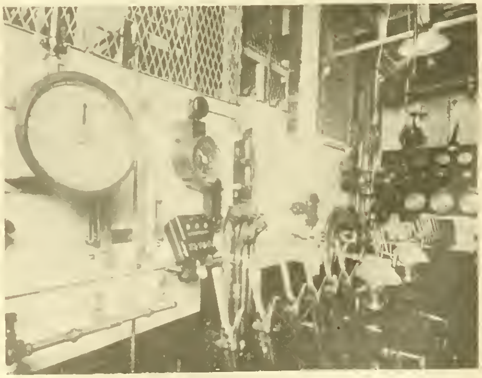

FIG. 4—CONTROL ROOM OPERATING LEVERS, LIQUID RHEOSTATS AND MOTOR SECONDARY BREAKERS AS VIEWED FROM THE STARBOARD SIDE

closed, thus continuing the alarm until the relay contacts are opened by hand.

The voltage relay does not operate in the case of clear circuits, as the three secondary voltages are balanced. In case of a low resistance ground on one lead, one transformer becomes short-circuited, thus impressing full generator voltage across each of the remaining two and the vector sum of the two transformer secondary voltages across the relay.

Ordinarily the ship will be stopped upon the warning of a ground and the grounded lead isolated, but if an emergency demands that operation continue, the relay can be disconnected to silence the alarm.

ELECTRICAL INSTRUMENTS ON CONTROL ROOM BOARD

The electrical instruments have black dials with white lettering and pointers and the scales are specially marked to facilitate taking quick readings. The following instruments are installed for the propelling machinery, the alternating-current instruments being operated from current and voltage transformers of suitable ratio.

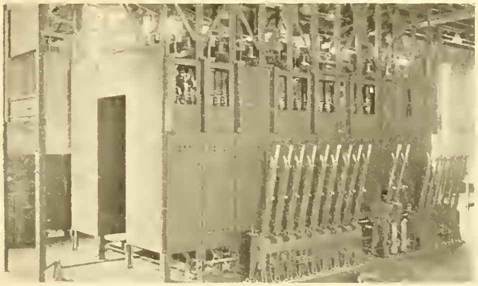

FIG. 5—THE CONTROL ROOM PRIMARY STRUCTURE

For Each Turbogenerator

One alternating-current, 4000 ampere ammeter.
One alternating-current, 4000 volt voltmeter.
One alternating-current, single phase, 15 000 kw. wattmeter, marked for three-phase balanced power.
One frequency meter marked in r.p.m., with three scales to indicate revolutions of the turbogenerator, of the motors on the 24 pole connection and of the motors on the 36 pole connection.
One three-phase power-factor meter.
One stability indicator.
One direct-current, 400 ampere field ammeter.
One direct-current, 400 volt, field voltmeter.
One main turbine governor stop position indicator.
One main turbine revolution indicator, 3000 r.p.m., magneto operated.

For Each Motor:—

One alternating-current ammeter with two scales, one 1600 amperes for the motors on the 24 pole connection and the other 800 amperes for the motors on the 36 pole connection.
One alternating-current, single phase watthour meter, connected to record balanced three-phase power.
One shaft revolution indicator 200-0-200 r.p.m., magneto operated.

All instrument transformer secondary leads come to terminal boards above the main panels for convenience in inserting testing instruments and for disconnecting the instrument wiring. Rear connected knife switches having testing terminal posts on the front are provided for all circuits. The current switches are double throw, and have their blades arranged so that the circuit is not broken in short-circuiting the current transformers or when inserting testing instruments.

The most important electrical instruments are the motor ammeters, the stability indicators and the field ammeters. The specified propeller speed is obtained by adjusting the turbine speed, indications of the former being obtained from regular readings of the mechanical revolution counter. The magneto-voltmeter speed indicators give instantaneous values of turbine and propeller speed and are useful for detecting anything abnormal in the operation of the machinery.

The motor ammeters are sensitive indicators of the load being carried by the motors, and of when the motors have fallen out of step with the generators. If the rudder is thrown hard over to the right the starboard motor ammeters will indicate much higher currents than the port motor ammeters, showing that the starboard propellers have the greater load. The stability indicator shows when the voltage of the generator is sufficient to enable the generator to carry the load safely under the given conditions.

A certain field current is necessary for maintaining a safe generator voltage for any given speed and condition of operation. The field voltmeter in connection with the field ammeter serves the purpose of giving the operators a general idea of the temperature of the generator field.

The wattmeter shows the power delivered to the propelling motors. Shaft horsepower can be calculated from the wattmeter reading by allowing for motor efficiency. The power-factor meter gives a fairly good idea of operating conditions in that it is an indicator of the relative excitation. A high power-factor indicates an economical excitation while a low power-factor indicates an excessive excitation.

GAUGES ON THE CONTROL ROOM BOARD

Black dial gauges having white markings and red markers to indicate the working pressures are installed for indicating the operating condition of the prime mover systems. One gauge panel is provided for each engine room and the gauges are connected to the following points:—feed water system, main steam line, main turbine steam chest, first stage inlet, auxiliary exhaust, main condenser vacuum, forced lubrication for bearings, governor control valve oil supply and oil line to the governor.

OTHER INSTRUMENTS ON THE CONTROL ROOM BOARD

The center panel carries red lamp indicators for the 240 volt direct-current feeders from the engine rooms, green and red lights for the main turbine power limiting devices and white lights for the main turbine throttles. It also has mounted on it the rudder indicator, the time clock and the revolution counter. The counter is mechanically connected through disengaging clutches, shafts and gearing to the four propeller shafts. The revolution counter gives the following records and indications:—

a—Revolutions of the individual shafts.
b—Average revolutions of the port, starboard and all shafts.
c—Average r.p.m. of port, starboard and all shafts can be ob-

tained by holding a train of gears in engagement for 30 seconds.

d—A movable pointer indicates on a dial the relative average speeds of the port and starboard shafts, which side is running the faster and how much.

e—Two additional sets of counters, only one set being in operation at one time, are clutched in electrically from the bridge and are used to record the all shafts average revolutions for any distance traveled by the ship.

TEMPERATURE INDICATOR FOR THE ALTERNATING CURRENT MACHINES

Each generator and propelling motor has six thermocouples imbedded in its stator windings, whereby the temperature in the slot can be read on a potentiometer mounted on the control room board. Three of the motor couples are in the 24 pole winding and the other three are in the 36 pole winding.

A link arrangement is used for connecting three of the six couples of each machine to a pair of dial switches and readings of only the three hottest couples in the case of the generators and the three couples in the operating winding in the case of the motors are taken on any run. The instrument measures temperatures up to 200 degrees C. Seven conductor cable consisting of six copper and one advance conductor connect the couples in the machines to the instrument panel in the control room. This cable is made up in accordance with Navy practice for interior communication cable.

CABLES

Varnished cambric insulation is used on all cables installed in machinery spaces. The direct-current cables are covered with a lead sheath and a steel armor overall and the largest single conductor cable used is 800 000 circ. mils. Round duplex cables are used for two wire circuits having conductors not larger than 60 000 circ. mils. The armored cables are cleated directly to the steel work.

Triplex cable is used for the 3400 volt alternating-current primary circuits and for the motor secondary circuits, each conductor being 500 000 circ. mils, and each cable carrying three-phase power. Two or more three-phase cables are connected in parallel depending upon the current to be carried.

The alternating-current cable was made up in accordance with the recommendations of a special committee of the A. I. E. E. which co-operated with the Navy Department on the general problem of cables for electrically driven ships. The cable insulation is of black varnished cambric and there are two coverings, the inner of reinforced rubber and the outer of lead. The manufacturer's test voltage on the cable was 20 000 volts for one minute. The rubber sheath forms a moisture proof protection for the cable in case the lead sheath becomes damaged.

The alternating-current cables terminate in special triplex terminals which have a wiped lead joint with the cable sheath. The outlets for the individual conductors are made moisture tight by special taping and the terminal is finally filled with insulating gum. The insulators through which the individual insulated conductors pass are of bakelite.

The primary cables carry not more than 375 amperes under maximum conditions and the inductive effects of their currents are practically neutralized. It is thus possible to run the alternating-current cables around and through steel work and bulkheads at will without the necessity of taking special precautions. The cable sheaths are not insulated from the cable supports, as there is no tendency for sheath currents to be induced. The cable rests in a pair of malleable iron blocks and a split lead sleeve is used between the sheath and the blocks for protecting the sheath against wear. The cable is supported approximately every two feet.

Brass bushings having rounded edges and liberal bearing surfaces are used where the cable pierces plates. Individual stuffing tubes are used where the cable pierces watertight bulkheads at right angles. For other angles, a cast bulkhead plate, through which all the cables pass, is used to make a watertight joint with the bulkhead.

The alternating-current generator leads are taken out below to a set of bus-bars to which eight triplex cables are connected. These cables run through the pump rooms and terminate above the bus-bars of the control room structure. The motor cables leaving the control room consist of two for the 36 pole leads, four for the 24 pole leads and six for the secondary leads.

The motor cables terminate on short bus-bars above the motors and flexible single conductor 500 000 circ. mil braid covered cables connect from the bus-bars to the motor terminals. These flexible cables are readily disconnected from the motor and can be swung out of the way when it is necessary to move the stator forward for the inspection or repair of the motor.

Lighting Sets on the U. S. S. Tennessee

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POWER for the auxiliaries and for lighting on the *Tennessee* is furnished by six 300 kw, 240/120 volt, three-wire generators, driven by steam turbines. Four of these turbines are built to operate condensing; the other two operate noncondensing and exhaust into the feed water heating system. The speed of the turbines is 6000 r.p.m., which is reduced through gears to 900 at the generator. The noncondensing turbines are capable of developing one-third overload for two hours, when operating with 250 lbs. steam pressure and 10 lbs. back pressure. The condensing turbine will carry one-third overload when operating at 200 lbs. steam pressure and 25 in. vacuum or 300 kw with 200 lbs. steam pressure and atmospheric exhaust.

The noncondensing turbines are of the single disc type with one row of blades, the blade speed being about 600 ft. per second. There are two nozzles with valves arranged so that either nozzle can be closed, the dimensions of the nozzles being such that with the large nozzle open about 60 percent of the total capacity of the machine can be carried, and with the small nozzle open, slightly less than 40 percent can be carried. Each nozzle has a suitable reversing chamber for re-directing the steam upon the rotor blades.

The condensing turbine is of the single-flow combination type, consisting of a three-row impulse element followed by fourteen rows of reaction blading. The glands on the turbine spindle are of the water seal type and therefore no steam escapes around the shaft on the noncondensing units, and no air gets into the cylinders on the condensing sets.

The governor is of the flyball type and is quite powerful. It is mounted inside of the reduction gear casing. This location of the governor is very satisfactory, particularly as it permits of generous lubrication of the moving parts of the governor without the escape of oil from the machine.

The oil pump is driven from an extension of the governor spindle and is located in the bottom of the gear case, which serves as a reservoir for the lubricating oil. The oil from the pump discharges through a strainer located on top of the gear case, and is so arranged that should the strainer become clogged the oil overflows to the passage which leads to the bearings. If the oil pump discharges more oil than the bearing will take, the level of the oil in this strainer box raises a little higher and the excess oil overflows through a passage leading back to the reservoir. This strainer box is provided with a cover which can be lifted off to examine the oil and observe the flow at any time when the machine is operating. At the same time the oil strainer can be removed for cleaning without interrupting the operation of the machines. A hand pump is provided for pumping oil through the system before starting.

An emergency overspeed governor is furnished to close the throttle valve should the turbine overspeed ten percent. This device consists of a small weight carried in a casing attached to the turbine spindle and designed so that the centrifugal force on the weight is overbalanced by the pressure of a spring, until the speed has been reached at which the device should operate. As the weight moves out, the centrifugal force on the weight increases much more rapidly than the scale of the spring, so that the weight snaps out quickly, once it starts to move. In its outer position, this emergency overspeed governor weight strikes a small lever which unlatches a fairly heavy weight which, falling freely, unlatches the throttle valve spring, causing the valve to close instantly.

Rather elaborate provisions are made to guard against the possibility of the throttle valve being opened at a time when the exhaust valve is closed. On the turbine cylinder there is mounted a small signal valve, which will blow when the pressure in the cylinder reaches about 15 lbs., thus indicating to the operator that he has an improper pressure in the cylinder. The throttle valve can be closed instantly by pulling a small lever adjacent to the hand wheel. If the pressure builds up to 20 lbs., an automatic device instantly closes the throttle valve. If, however, the pressure builds up to 25 lbs., a large relief valve on the turbine cylinder will open and prevent the pressure exceeding 50 lbs. with the throttle valve wide open and the exhaust valve closed. This latter relief valve is piped to atmosphere. In addition, both hand and electrical devices are provided for closing the throttle valve from a distance. The noncondensing turbines are not equipped with the device to close the throttle valve automatically at a predetermined pressure in the turbine cylinder, as these machines serve as exciters to the main unit and it was thought better to avoid any possible risk of this device shutting down the turbine, should the back pressure build up.

The governor valve is connected directly to the governor without the intervention of any form of relay. The noncondensing turbines have only one governor valve. The condensing turbines have two valves, the primary valve being designed to pass sufficient steam to carry full load when the turbine is operating condensing and the secondary valve being designed to carry one-third over-load when the turbine is operating condensing. To carry the full load on the condensing turbines when they are operating noncondensing a hand by-pass valve is provided.

The lubricating oil is cooled by passing it through an oil cooler as it is discharged from the pump on its way to the bearings. The cooler is similar to a small surface condenser, with the cooling water passing through the tubes and the oil passing several times back and forward over the tubes.

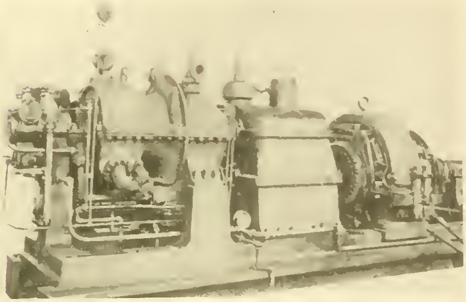

FIG. 1—TURBINE END VIEW OF 300 KW DIRECT-CURRENT GEARED LIGHTING SET

An interesting feature of these generator sets is that the generator is built with only one bearing, the inboard bearing being omitted and that end of the shaft coupled solidly to the gear shaft, in this way greatly improving the operation and at the same time affecting a very material reduction of the length of the unit.

The reduction gears are of the Melville-MacAlpin type and have the pinion located on top of the gear, so that the turbine and generator are on the same center line.

GENERATORS

The generators are of the same type for both the condensing and the noncondensing sets. Each has a cast steel frame split on a horizontal center line. Special field pole construction makes possible very close voltage regulation.

The main poles are laminated and are located symmetrically with respect to the center line of the frame. The commutating poles, which are shorter than the main poles, are of solid steel. These are offset from the center line of the frame and lie toward the rear of the machine. By this means the length of the wiring around the frame connections for the commutating poles is made a minimum. There are six main poles and six commutating poles.

The brushholder brackets are carried by a cast-iron rocker ring which fits into a recess in the field frame. The brush arms are of the washboard type, made of cast-iron. The ends of these are fastened rigidly to a ring formed of segments of micarta. Brass brushholders of the box type are used. The brushholder springs have a special enamel finish baked on. Bolts and nuts one-half inch in size or under are sherardized.

The armature is of such size that the punchings are keyed on the spider. Mica insulated armature coils are held in open slots by fiber wedges. Banding is used to secure the front and rear portions of the coils extending beyond the core.

The commutator is built upon a spider which is pressed and keyed onto the shaft. Four brass collector rings, which are shrunk on a mica-covered cast iron hub, are pressed onto the shaft in front of the commutator. The current from the collector rings is conducted by means of cables which pass through the deck plates within the bedplate recess under the commutator, to two compensators or balance coils mounted on the engine room bulkhead. From the middle points of these coils the neutral wire of the three-wire system is taken. The compensator windings consist of four pan-cake coils mounted in shell type punchings. The individual coils are bakelized, varnished and dried thoroughly. The assembled coils and punchings are dipped four times in a suitable varnish and baked after each dipping.

When used with these compensators the generators, operating at 240 volts with an unbalanced load of 43 percent, will maintain a voltage balance of not less than 117 and not more than 123 volts between the neutral and outside wires.

The terminals are arranged for six 650 000 circ. mil cables for the main leads and four 650 000 circ. mil cables for the equalizer leads. The shunt field leads, positive main and half of the equalizer leads are on one side of generator; the remaining leads are on the other side. The terminals on both sides are covered by brass screens.

The shunt field rheostat is designed for a total range of close adjustment from five percent above to ten percent below rated voltage. The variation is not more than one volt per step between 230 and 250 volts at full load. The rheostat has sufficient resistance to reduce the voltage almost to zero with the machine on open circuit, comparatively high resistance steps being used on the lower end of the range. A rheostat with

FIG. 2—GENERATOR END VIEW OF 300 KW DIRECT-CURRENT GEARED CONDENSING TURBINE SET

two face plates is used. A total of 158 contact buttons are connected to tube type resistor units between the face plates. Contact arms are staggered so that voltage adjustment is possible over 154 steps.

In order to take the generator off the line automatically when the overspeed governor or the overpres-

sure trip has functioned and the throttle valve closes, the circuit breaker trip switch is mounted near the upper end of a trip weight lever. Whenever this lever is released, either by the action of the overspeed governor, by the overpressure trip or by hand, an electrical connection is made through a spring closed switch to the shunt trip coil of the engine room circuit breaker. This disconnects the set electrically.

In addition to furnishing power for the engine room auxiliaries, it is intended that the noncondensing units will supply, in connection with the booster sets, excitation for the main propulsion generators. However, by means of suitable switchboard connections, the condensing sets also can be made to serve this purpose.

Should both booster sets become inoperative, voltage adjustment of one of the 300 kw generators, to which only the fields of the main generators are connected, will make it possible with but little inconvenience, for the ship to proceed under full power, if necessary. The voltage adjustment of these sets is intended for this purpose only in an emergency.

All the generators are flat compounded to within one volt either way from 240 volts normal at no-load and full-load points. The variation from a straight line drawn between the no-load voltage point and a point halfway between the full-load points of the ascending and descending curves does not exceed four volts.

Condensing Equipment and Oil Cooling System for the U. S. S. Tennessee

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THE condensing apparatus serving each of the main turbines in each engine room of the *Tennessee* consists of: One main surface condenser; one main condenser circulating pump; one main condenser condensate pump; three main condenser air ejectors; and one main condenser air separator.

The condensing apparatus serving each of the 300 kw condensing units in each engine room consists of one dynamo surface condenser; one dynamo condenser circulating pump; one dynamo condenser condensate pump; two dynamo condenser air ejectors; and one dynamo condenser air separator.

MAIN SURFACE CONDENSERS

The main surface condensers contain approximately 11 616 sq. ft. of cooling surface, measured on the outside of the tubes. Each condenser is equipped with 6604, 5/8 in. outside diameter, No. 16 BWG tubes, having an active length of 10 ft. 9 in. The arrangement of tubes and design of the water boxes are such as to cause the cooling water to make two passes through the tubes.

The condenser shells are made of boiler plate. The exhaust trunk, or breeches connection between the turbine exhaust openings and the condenser is integral with the condenser shell and is also made of boiler plate. The condenser shell is rigidly seated in a steel cradle, the turbine and condenser expansion being taken up by copper expansion joints inserted between turbine exhaust openings and the exhaust trunk.

The condenser is designed to produce vacua not less than shown in Table I, measured in the turbine exhaust chamber, when condensing the quantities of steam and circulating the quantities of 60 degrees F. water therein tabulated.

MAIN CONDENSER CIRCULATING PUMP

The circulating pump for supplying cooling water to the main condenser is of the double inlet volute single-stage type with two runners, as shown in Fig. 1. The casing is divided into two parts, at the axis, and in a horizontal plane. The suction and discharge connections are integral with the lower half of the pump casing, thus allowing easy removal of the upper half without disturbing any connection of piping or the foundation.

The rotating element consists of two bronze runners and a steel shaft covered with keyed bronze sleeves to hold the runners in position, and to protect the shaft

TABLE I—CONDENSER PERFORMANCE

Lbs. Steam Condensed per Hour	Gallons per Minute Water Circulated	Guaranteed Vacuum Referred to 30 in. Bar
159750	10000	28.4
109540	15000	28.67
106850	15000	28.7
40190	9500	29.15

from the corrosive action of sea water. For further protection, red fibre packing rings are inserted between the sleeves and the runners. In fact, all parts coming in contact with water are made of bronze.

The main circulating pump is motor driven and with its drive is mounted on a continuous bed plate. The pump is direct connected to the motor by a flexible coupling.

The set is designed for adjustable speeds because the maximum capacity of the pump is greater than the capacity required for normal operation, thus permitting it to be operated at the proper speed to suit any conditions of circulating water temperature or load on the condenser. For this reason, the pump is operated with the suction and discharge valve wide open, thus insur-

ing maximum pump efficiency incident to any speed. This pump has a maximum capacity of 19 000 gallons per minute against a total head of 30 ft. at a speed of 700 r.p.m.. It is driven by a 235 hp motor having speed adjustment from 350 to 700 r.p.m.

An Open Motor, with split frame and brackets, is used. Drip proof canopy covers have been added since installation on shipboard. For marine service, the armature insulation is given special moisture resisting treatment. To prevent the spilling of oil due to the rolling of the ship, caps are used on the oil stand pipes. The bearing housings are provided on the inside with felt gaskets through which the shaft passes. These gaskets prevent the passage of oil into the motor windings or out upon the commutator.

The Controller has a multiple switch starter mechanically interlocked with the main circuit breaker. The armature resistance is cut out in six steps. The switches are interlocked so that they will close in proper sequence, each switch being locked in by the switch which follows it, and the entire group being held closed by the main circuit breaker. The interlock arm moves, whether the circuit breaker is being closed or opened, so that the starter is tripped before the circuit breaker contacts are made, in case the starting switches have

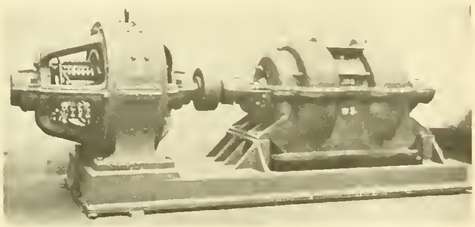

FIG. 1—MAIN CIRCULATING PUMP

been closed in advance of the circuit breaker. The no-voltage trip for this controller is on the circuit breaker.

The motor is stopped by tripping the circuit breaker and the starting switches open automatically upon the opening of the circuit breaker. Its speed is regulated by a separate field rheostat. A shunt contactor controlled by a vibrating relay in the armature circuit short circuits the field rheostat during starting. The relay opens after the starting operation is completed and the motor automatically comes up to the speed corresponding to the setting of the field rheostat.

The armature resistors for the auxiliary motors are designed to carry 150 percent normal load for one minute, and 200 percent normal load for twenty seconds without reaching a temperature which is injurious to the material.

EJECTING EQUIPMENT

In the removal of non-condensible vapors and condensate from the condenser it is desirable to cool the former as much as possible, while it is equally undesirable to cool the latter, which is to be returned at once to the boiler. In most surface condenser installations, this is accomplished by withdrawing the noncondensible vapor and condensate separately, the former after it has been cooled by contact with a bank of cold tubes, isolated for that purpose, the latter with as little tube contact as possible after condensation has occurred.

When separate machines are used, the system is described as "wet and dry." This system is employed on the *Tennessee,* where high vacuum is required, However, in many plants the owners have seen fit to compromise in the matter of final temperatures, and to remove both noncondensible vapors and condensate with a single pump. This system is described as "wet," and is also employed on the *Tennessee* to serve in the capacity of a stand-by. The system as installed comprises independent condensate pumps, air ejectors and air separators.

CONDENSATE PUMPS

The main condenser condensate pump is of the vertical shaft, double inlet, volute, single-stage type, with a single runner. The casing is divided into two parts on a horizontal plane, perpendicular to the axis of the pump. The complete rotating element, the gland and bearing, are integral with the upper half of the casing. The lower half, or pump body, carries both the inlet and water discharge connections, thus permitting easy removal of the top half, including the rotor, without disturbing any connection of piping or the foundation. This pump has but one bearing, which acts merely as a guide, and it is lubricated by water from the discharge of the pump. The weight of the rotor is carried by the thrust bearing of the motor.

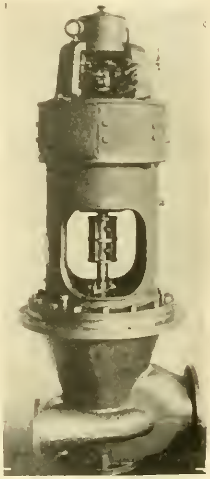

FIG. 2—MAIN CONDENSATE PUMP

The suction side of the pump casing is equipped with a vent connection, to relieve the pump constantly of any accumulation of vapor, which has a tendency to be given off, owing to the water approaching the boiling point of the vacuum at the pump suction. The presence of this vapor would cause the pump to become "vapor bound." In other words, instead of the pump runner being constantly full of water alone, it would be filled with part water and part vapor. This vent, therefore, is connected to the air piping between the condenser and the ejector, and is arranged as direct as possible, in order to free the interconnecting piping of any pockets that might otherwise prevent proper drainage to the pump.

The slightest air leak on the suction side of the pump will result in reduced capacity and consequent loss of efficiency. For this reason the gland is fitted with a water seal, the sealing water being supplied from a source separate from the pump. In addition to this an extra precaution against air leaks is provided in that the stuffing box is under pressure from the discharge of the pump. A slight water leak along the shaft indicates that the gland is sealed, and since this leakage is fresh water, it is led to the drain tank to which is led the drainage from the main turbine.

Motor—The characteristic of the condensate pump is such that the head it will discharge against is practically constant for varying amounts of condensate; therefore adjustable speeds are unnecessary. This pump, however, is driven by a 19 hp, 1700 r.p.m., adjustable-speed compound wound motor and while the capacity

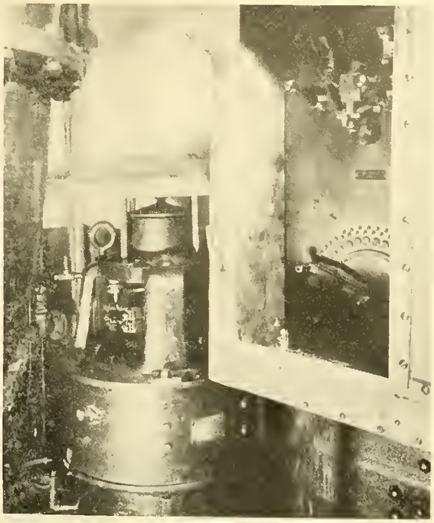

FIG 3—SHIPBOARD INSTALLATION OF MAIN CONDENSATE PUMP AND MOTOR CONTROL

is considerably greater than the requirements of service, an increase in head will result from an increase in speed. The pump is designed for a capacity of 500 gallons per minute against a total head of 70 feet.

The assembly of the unit without the canopy cover is shown in Fig. 2. A speed adjustment from 1400 to 1700 r.p.m. is possible. Marine fittings are employed. A ship's roll up to 30 degrees will not cause the spilling of oil from motor bearings. A canopy drip-proof cover has been installed over the motor, as shown in Fig. 3.

Controller—The controllers for the engine room pump motors are located close to the motors which they control, as shown in Fig. 3, and are provided with a two-pole overload time limit circuit breaker, a manually-operated starting rheostat and no-voltage protection. The circuit breaker has independently closing arms and serves also as the line switch. Speed regulation is obtained by field control.

The controllers for all motors of 25 hp and below have starting and field regulating rheostats of the sliding arm type, arranged so that the motors are started on full field. The rheostat has two arms, the upper for the field contacts and the lower for the armature contacts. The upper arm has the handle and carries the lower arm with it when starting the motor. After both arms have been moved to the running position the starting arm is held by the no voltage mechanism and the field arm is moved back to increase the motor speed to the desired value. The motor is stopped by tripping the circuit breaker, and the rheostat automatically returns to the off position, the starting arm carrying the field arm with it.

AIR EJECTOR

The main condenser air ejector is an apparatus for removing air from the condenser at a low absolute pressure by means of steam jets, to compress and exhaust the air against atmospheric pressure. All parts entering into the construction of the Westinghouse LeBanc air ejector, Fig 4, are of bronze. The ejector consists of two stages arranged in series. The first stage includes

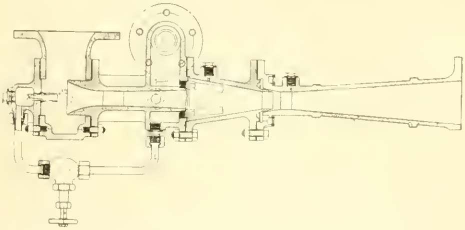

FIG. 4—SECTION THROUGH MAIN CONDENSER AIR EJECTOR

a single expanding nozzle which receives steam from the upper steam chest, and after expanding it to the desired pressure, discharges it through a receiving chamber into the combining tube and diffuser. The receiving chamber communicates with the condenser where the air is entrained by friction of the air with the steam jet. The discharge end of the first stage delivers the fluid traversing it, to the inlet end of the second stage ejector. The outlet of this diffuser is surrounded by a series of expanding nozzles which receive and expand the second stage steam to the desired pressure, discharging it into the lower mixing chamber. The mixture from the first and second stage ejectors is further compressed and discharged through the diffuser to a line leading to the air separator.

The ejector requires no adjusting, so that the only trouble that may be experienced is the clogging up of the nozzle throats. If the steam strainers are cleaned regularly this will not occur. It has a further advantage over other classes of air removal machinery in that it utilizes high velocities in the removal of the air, which is accomplished by the friction of the air with the fine jets of steam, resulting in the smallest possible piece of

apparatus. On the other hand, in the case of reciprocating pumps, the air is removed by displacement which, at a high vacuum, requires a machine of large cubical content, owing to the large volume of air to be handled.

When supplied with steam having a pressure at the ejector inlet of 125 lb. per sq. in. gage, each ejector serving the main condenser has an air removal capacity of 36 lb. of free air per hour, when exhausting air from

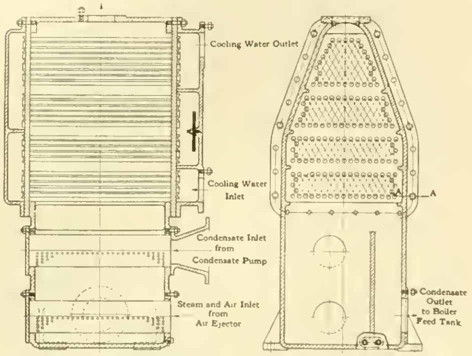

FIG. 5—SECTION THROUGH MAIN CONDENSER AIR SEPARATOR

a 28 in. vacuum, and 27 lb. per hour from a 28.5 in. vacuum, referred to a 30 in. barometer. Three ejectors are supplied for service in connection with each main surface condenser, two of which will remove the air under normal conditions of operation, the other serving as a stand-by.

THE MAIN CONDENSER AIR SEPARATOR

The air separator, shown in Fig. 5, receives the air and steam from the ejectors, one separator being furnished in connection with the three ejectors serving each main condenser. The function of the air separator is to condense the ejector steam, and automatically separate the entrained air which is allowed to escape to the atmosphere through the air vent at the top, thus insuring complete separation of air. The air separator, is in reality, a combination jet and surface condenser. The jet condenser uses as a condensing fluid the condensate from the main unit; the surface condenser receives cooling water from the main circulating system.

Under normal conditions of operation, there is sufficient condensate to condense the steam in the jet portion of the separator, in which case all the heat of the motive steam is regained in heating the feed water. During times of light load, when there is not enough main unit condensate to condense the ejector steam such condensation takes place in the surface portion of the separator, so that the loss of heat from this source is practically negligible. Thus the efficiency of the ejector is practically 100 percent.

From the separator the condensate overflows into the feed and filter tank. The air separator weighs approximately 1425 lb. It contains 90 sq. ft. of cooling surface, requires 200 gallons per minute of cooling water, and has a capacity for 4400 lbs. of steam and 195 000 lbs. of condensate per hour.

OIL COOLER CIRCULATING PUMP

Except for the fact that this is a single-runner pump, and of comparatively smaller capacity, the pump for circulating the cooling water for the oil cooler is the same as the main circulating pump, in so far as construction, materials, etc, are concerned. It has a capacity of 300 gallons per minute against a total head of 115 feet and is driven by an 18 hp motor running at a speed of 1750 r.p.m. Fig. 6 shows this unit as installed on shipboard. One oil cooler circulating pump is installed in each engine room. A canopy is placed over the motor, as shown, to protect the windings from dripping condensate, leaking steam, water and oil. That this precaution is necessary is obvious from number of pipes, valves etc. shown in the vicinity of this set. A controller similar to that shown in Fig. 3, is used to give a speed adjustment of 583 to 1750 r.p.m.

LUBRICATING OIL PUMPS

The lubricating oil pumps are of the rotating plunger type. Each pump is capable of delivering 250 gallons of lubricating oil at 100 to 160 degrees F. against a discharge head of 185 feet with a maximum pump speed of 600 r.p.m. Fig. 7 shows the motor-driven unit installed on the *Tennessee*.

The rotation of the cylindrical piston on the cam drive shaft produces a vacuum in the cylinder. This causes the oil to flow through the suction port and follow the piston until the cylinder is completely filled. The port in the piston slide is then closed mechanically, and remains so until the cam or piston has completed its full revolution. When the piston passes the suction port it automatically opens the discharge port, and immediately begins forcing the oil out into the cylinder chamber, at the same time drawing in a new supply.

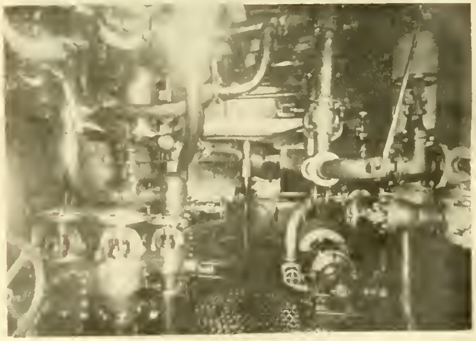

FIG. 6—SHIPBOARD INSTALLATION OF THE OIL COOLER CIRCULATING PUMP

All parts of the pump except the drive shaft are arranged in duplex, opposed at an angle of 180 degrees. There is no mechanical contact between the pistons and the cylinder. The ports are not congested by valves

or springs. A 25 hp, 400 to 600 r.p.m. compound-wound motor is directly connected to the lubricating oil pump.

In addition to the two motor-driven pumps described above, two similar pumps are turbine driven through reduction gears. The latter are used as a stand-by, and come into service when the drop in oil pressure for the bearings reaches that value for which the automatic starting valve is set. An overspeed governor prevents the speed of the driving turbine from exceeding a predetermined safe value.

DYNAMO CONDENSING SYSTEM

The apparatus used in connection with the four 300 kw condensing units, two of which are installed in each engine room, is of the same general construction as that used for the main units, though of relatively lower capacities.

The Circulating Pump supplies the dynamo condenser with cooling water, and is designed to have a capacity of 2000 gallons per minute against a total head of 20 feet. It is driven by a 17 hp. motor running at a speed of 700 r.p.m. Like the main condenser circulating pump, it is an adjustable speed pump, thus permitting operation at the proper speed to suit any condition of circulating water temperature and load on the condenser.

The Condensate Pump withdraws the condensate from the dynamo condenser, and is designed to have a capacity of 75 gallons per minute against a total head of 70 feet. It is driven by a 6 hp. motor which has an adjustable speed rating of 1500 to 1800 r.p.m. and is

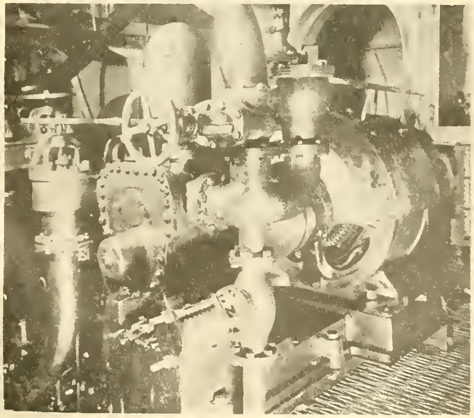

FIG. 7—MOTOR DRIVEN LUBRICATING OIL PUMP

similar in construction to the vertical motor driving the main condenser condensate pump.

The Air Ejector has a free air removal capacity of 18 lbs. per hour when exhausting air from 28 in. vacuum referred to a 30 inch barometer. In the case of the dynamo condenser, two air ejectors are installed, one of which has sufficient capacity to remove the accumulated air, while the other serves as a stand-by. Fig. 8 shows the manner in which these ejectors are mounted on shipboard.

FIG. 8—MOUNTING OF AIR EJECTOR ON SHIPBOARD

Air Separator—As in the case of the main condenser, one air separator is installed in each engine room to receive and condense the exhaust steam from the ejectors serving the dynamo condenser, the entrained air being automatically separated and allowed to escape through a vent at the top. The air separator is identical in construction with the main condenser air separator, though of relatively smaller capacity. It contains 35 sq. ft. of cooling surface, requires 100 gallons per minute of cooling water, and has a capacity for 1980 lbs. of steam and 110 000 lbs of condensate per hour. It weighs approximately 850 lbs.

ELECTRIC MOTOR DRIVE

The large proportion of electrically-driven engine room auxiliaries is noteworthy. Where there is already sufficient exhaust steam available for feed water heating, heating of the ship, etc., the electric motor drive is more economical than that of steam. This is especially true in connection with the small ratings required for all but the main circulating pumps. Weight is reduced to a minimum for these small motor drives. The speed of the motor can be made suitable for the application without the use of reduction gears. This may be exemplified in the case of the two forms of drive for the oil pumps which operate at 600 r.p.m. In this particular instance the motor-driven outfit has also the advantage of lower first cost. Obviously the motor-driven pump will be less noisy and attended with less vibration than the geared turbine drive, and the weights of the two types are nearly the same. For auxiliaries in the above class, the first cost of the electric drive is usually a trifle more than that of the steam drive. The more efficient operation of the former over the latter is the chief reason justifying electrical equipment. A further important consideration is the fact that the cost of maintaining electric feeder cables is less than that of steam lines and the care of the electric equipment itself is not so great as that of steam.

The Control of the Secondaries of the Main Propulsion Motors of the U. S. S. Tennessee

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THE speed control of the main propelling motors of the *Tennesee* is obtained by varying the primary voltage and frequency, this being done at the turbogenerator. In order to accelerate the motors up to speed to allow the short-circuiting of the motor secondaries, as in starting, and in order to decelerate and accelerate the motor in the opposite direction as in stopping or reversing the ship, liquid rheostats are used for inserting and cutting-out resistance in series with the secondary windings. There are four propelling motors and so four rheostats are used. However, the rheostats are made in pairs, or two double rheostats, as the construction is convenient, economical of space and allows the operation of both rheostats of the pair in case of an accident to one pump, motor, or motor supply line.

One of the double rheostats is shown in Fig. 1. It consists of a sheet steel tank, two sets of electrode units, a cooling system and two motor driven centrifugal pumps. The tank has two main sections, of which the lower is the liquid storage tank and contains the liquid cooling coils. The upper section is divided into three sections, consisting of two electrode chambers (one for each motor) and between them a smaller chamber known as the "overflow chamber," the bottom of which opens into the lower or storage tank.

The storage tank is the reservoir for the electrolyte and also contains the cooling coils of the cooling system. Outside and on each end of this tank is mounted a direct-current shunt motor, a centrifugal pump, outlet and inlet pipes and valve. The pump receives its liquid from the bottom of the storage tank and delivers it to the bottom of the electrode chamber above.

Each of the two electrode chambers has two electrolyte inlets and two outlets. The main inlet is at the bottom towards the end and is the direct supply from the pump. Above this inlet is an insulated barrier which prevents jetting above the inlet and distributes the flow over the electrode chamber. The second inlet is an opening between the two electrode chambers and is normally closed by a valve. This valve is opened in an emergency when one pump or its motor is out of service, and then the other pump supplies the two electrode chambers with electrolyte. The two outlets in each electrode chamber are located in the wall of the common overflow chamber at different levels and they determine the height of the liquid in the electrode chamber. The lower of these openings is controlled by a butterfly valve which is opened and closed, together with the similar valve in the other electrode chamber, through a system of levers and bell cranks by a control lever on the operating stand in the control room. This valve, when open, keeps the level of the liquid down to the minimum liquid level. The upper opening or outlet is a rectangular weir and determines the upper or maximum liquid level in the chamber.

The cover plate of the electrode chamber carries the electrodes by means of special moulded insulators.

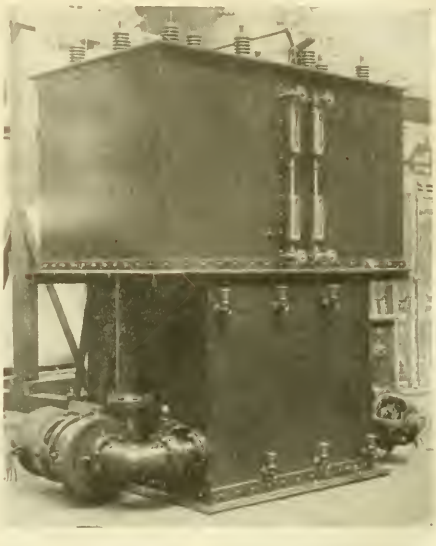

FIG. 1—DOUBLE LIQUID RHEOSTAT

The complete electrode unit can be raised or removed for examination and insulator cleaning by means of the eye bolts on the cover. The complete electrode unit is shown in Fig. 2.

The electrodes consist of parallel steel plates, There are seven long plates for the three phases, the two outer ones being of the same phase in order to give approximately equal resistance between phases. With the liquid at low level the seven plates only are immersed and, as they are relatively far apart and the contact area with the electrolyte is small, a high resistance between phases is obtained. Shorter electrodes are placed between the seven long plates in order to decrease the resistance between phases more than the

proportionate rise in liquid level would give and to obtain a low resistance across the motor slip rings before short-circuiting them. The ratio of maximum resistance to minimum resistance with one definite percentage of electrolyte is 15 to 1. The electrolyte is a

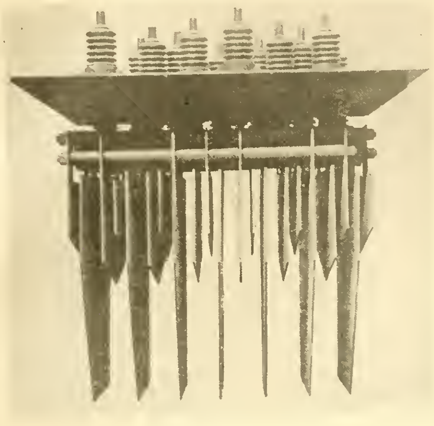

FIG 2—COMPLETE ELECTRODE UNIT

Electrodes are suspended from cover plate of the electrode chamber.

low percentage solution of sodium carbonate. The level of the liquid and its temperature can be observed by a liquid level gauge and thermometer in each electrode chamber.

The operation can be followed by referring to Fig. 3. The electrolyte flows continually from the storage tank through the pump to the electrode chamber and through the lower overflow to the overflow chamber and back into the storage tank. The rate of flow can be adjusted by the speed of the pump motor and by the valve in the pump supply line. The lower overflow is kept open in the normal *off* condition, and so the high resistance is maintained in readiness for acceleration or deceleration of the propelling motors. With the generated voltage and frequency at a predetermined value and the proper set-up switches closed, the operator moves the *liquid rheostat lever,* and this lever closes the lower overflow and the electrolyte rises at a predetermined rate in the electrode chamber, until it runs over the upper overflow. The increased immersion of the electrodes decreases the resistance between electrodes of the different phases. The electrode terminals of the phases are connected to the slip rings of the secondary of the motor and so the resistance between slip rings is decreased. When the operator observes in the gauge that the maximum level has been reached, he throws the *secondary lever* which closes a circuit breaker, thus short-circuiting the motor secondary's slip rings. The *liquid rheostat lever* is then moved to the initial position to open the lower overflows and the liquid is lowered to the minimum level to be in readiness for another operation.

The amount of resistance and the rate of decreasing the resistance are determined not from the starting of the main motor from rest to full speed, but rather for the condition of reversing from full speed ahead to full speed astern. When the ship is going full speed ahead and the power is cut off from the propeller motors, the speed of the propellers will drop to approximately seventy percent of the full speed. To bring the propeller to rest and to reverse it, the motor primary is connected to the line for the opposite rotation and the motor is then rotating at 170 percent slip, based on full speed astern. To bring the propeller to rest, it is necessary to exert nearly full-load torque during part of the deceleration time, and over 25 percent of full-load torque to hold the propeller at rest. Before reversing, the turbogenerator is adjusted to give half voltage and half frequency on the motor primary. The resistance between phases of the rheostat at minimum level is made to give the full-load torque at near 170 percent slip. The resistance at maximum level is made sufficiently low to bring the motor speed near enough to synchronous at full-load torque to allow the short-circuiting of the secondary slip rings with 150 percent of full-load motor current. The time required to decelerate and accelerate the propeller, shaft and motor rotor from full speed ahead to full speed astern is based on the propeller characteristics and the moments of the parts. With normal speed of the pump motors and with the pump valve open, approximately fifteen seconds are required for the liquid to rise, and twenty seconds for it to fall.

As the rheostats are not used for speed control of the propelling motors, they only need to be able to take care of a certain number of consecutive starts and reversals.

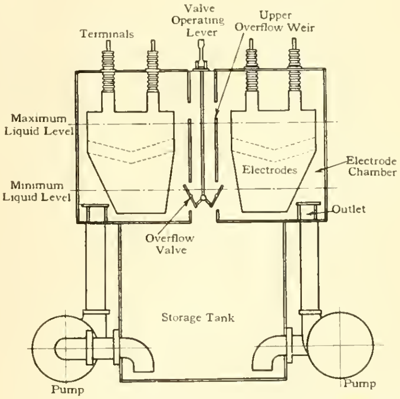

FIG. 3—CROSS SECTION OF DOUBLE LIQUID RHEOSTAT

The rheostats are located in the main control room and immediately behind the operator's platform and levers, one double rheostat on each side of the center. The cooling coils in the storage tanks are adapted to use sea water.

The Stability Indicator

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WHEN alternating-current motors were adopted for the propulsion of battleships, there were many new problems which had to be solved. One of these was to produce an indicator that would show when the induction motors were near or at the drop-out point.

The speed of the ship is controlled by changing the frequency applied to the motors, the power output of the generators and the number of poles on the motors. At each operating speed of the ship, there is a value to which the field excitation can be reduced and which is sufficient to hold the motors in step. It is desirable to operate the ship on as low a fuel consumption as possible and therefore any reduction that can be made in the field excitation is a direct gain due to the decrease in the sum total of losses. Also with the lower excitation, and thus the lower voltage, the power-factor of the system is improved. However there is danger that the excitation will be reduced to the range of unstable operation and the motors will pull out of step. To avoid this difficulty and to show how near the unstable point the particular running condition is, the stability indicator was developed.

This instrument, Fig. 1, consists of two elements whose moving systems are mounted on the same shaft, and whose torques oppose each other. One is an alternating-current ammeter element whose indications are relatively independent of frequency throughout the ranges used, and which measures the current which the generator feeds to the system. The other element is an alternating-current voltmeter which has a reactor in place of the usual resistance, so that its indications are inversely proportional to frequency and directly proportional to the generator voltage. The quantity which is measured by this voltage element is a function of the excitation of the generator field. Therefore, for a given running condition, if the field excitation is reduced, the generator voltage is reduced and the voltage element of the stability indicator becomes weaker. At the same time the current which the generator feeds to the system increases and the current element of the stability indicator becomes stronger. This causes the instrument to indicate on that portion of the scale which shows that the decrease in excitation is approaching an unsafe operating condition.

When the excitation is raised, the voltage of the generator becomes higher and the line current becomes lower, causing the voltage element of the stability indicator to have a relatively greater effect than the current element, so that the instrument will indicate that the excitation is higher than necessary. If the field excitation is increased further, the induction motors will draw an excessive amount of wattless current which will cause an increase in the current output of the generator. This increase in current may be sufficient actually to overcome the effect of an increase in voltage and the indicators of the instrument will tend to show that this is a poor operating condition, but not to the same extent that a decrease in excitation will give.

The scale of the instrument covers an arc of 300 degrees. The instrument has a control spring which normally holds the pointer at the center of the scale. The scale may be divided into zones of different colors, one indicating dangerous operation or low excitation, another indicating safe operation, and another indicating excessive excitation. Each element operates on the induction principle and the movement is light and very rugged, so that there is no danger of damaging the instrument under starting conditions or during manipulation when the current values are liable to be high. One instrument is required for each generator.

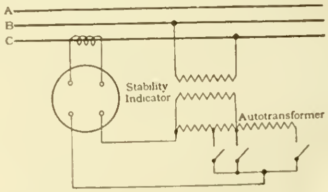

FIG. 1—WIRING DIAGRAM OF THE STABILITY INDICATOR

On the U. S. S. *Tennessee* there are three combinations for normal operation. One is with two generators and four motors with twenty-four pole windings. Another is with either generator and four motors with 24 pole windings. The third is with either generator and four motors with 36 pole windings. With any one combination there is a certain ratio between the impressed voltage and the line current which must be maintained for stable operation. In order that the instrument may indicate correctly under all the above combinations, it was necessary to supply an autotransformer which is connected to the secondary of the voltage transformer so that the voltage applied to the instrument could be changed for each combination. The shifting of taps on the autotransformer is accomplished by means of auxiliary switches which are operated automatically when the main switching is done to obtain the above combinations. Therefore no matter which combination is in service, the instrument will always indicate the correct value of field excitation on the generator for stable operation.

Main Turbines and Turbine Speed Control for the U. S. S. Tennessee

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THE main power plant of the *Tennessee* consists of two duplicate steam turbines of 16 000 brake horse-power capacity and with a nominal full speed of 2075 r.p.m. They are of the impulse and reaction double-flow type and are designed to take steam at 250 pounds gage pressure at the throttle, 50 degrees superheat, 28.5 inch vacuum. The turbines have an economical operating speed range from about 1500 to 2200 r.p.m.

A view of the turbine from the generator end is shown in Fig. 1, and Fig. 2 shows a view from the opposite end, both illustrations showing the turbine on the test floor, without lagging, and connected to a water brake instead of the generator. When installed in the ship, the generator occupies the position here taken by the brake, being connected to the turbine by means of a suitable coupling.

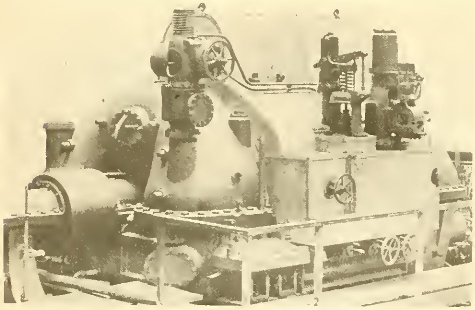

FIG. 1—MAIN 16 000 HORSE-POWER TURBINE VIEWED FROM GENERATING END

The turbine and generator rotors are each carried on a pair of babitted bearings, the pedestals for the generator bearings being separate castings secured directly to the seatings. The coupling-end turbine bearing is carried by the end of the turbine cylinder, which in turn is supported on the sides at the center line, by "chairs", secured rigidly to the seatings. The turbine bearing at the opposite end is held by a pedestal part of the cylinder casting, resting on the seating and, like the cylinder supports at the opposite end, resting on the chairs, free to slide endwise with the expansion or contraction of the cylinder. The cylinder as a whole is prevented from moving by being bolted rigidly to the inboard generator pedestal.

High-pressure steam is admitted to the turbine at approximately the center. It first passes through a strainer, then through a throttle valve which may be opened or closed by hand or which will close automatically when the turbine reaches a predetermined speed above that of normal full speed. The steam next flows through the "governor valve" controlled by a special form of governor which is made to operate the turbine at any desired speed from full to about one-fourth full speed. Passing next through a group of hand-operated valves, any or all of which may be opened, depending on the load to be carried, the steam enters the nozzle chambers of an impulse element. Here it expands in suitable nozzles, passes through an impulse wheel, consisting of two moving and one stationary row, and then expands through a single flow intermediate reaction portion of the unit. It then divides, one-half passing directly into a low-pressure reaction portion and the other half through a large oval shaped pipe over the top of the cylinder to a similar reaction element on the other end of the machine. From each half the steam passes downward through an exhaust opening into the surface condenser located athwart ship directly below the turbine. These exhaust connections are provided with expansion joints to avoid restriction of the end movement of the cylinder caused by expansion and contraction.

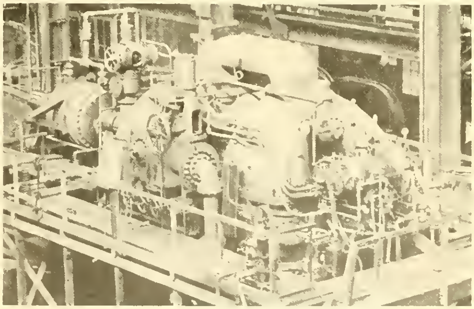

FIG. 2—MAIN TURBINE ON THE TEST FLOOR

Provision is made for the admission to the main turbine at a suitable point of low pressure or exhaust steam from the various auxiliaries which is not needed for heating the feed water, thus utilizing the energy available when this steam is allowed to expand from the auxiliary exhaust pressure to that of the vacuum in the main condenser. This steam is admitted through a hand controlled valve and also a butterfly valve controlled by the same overspeed device that actuates the automatic main steam throttle. There is also a connection from this low-pressure steam inlet directly to the exhaust chamber of the turbine, provided with an automatic valve controlled by the steam governor valve.

This auxiliary exhaust steam by-pass valve opens when the main governor valve has closed, allowing the steam to go direct to the condenser, instead of through the low-pressure portion of the turbine, and thus preventing overspeeding even if there is a sufficient amount of exhaust steam available to run the turbine without the use of any high-pressure steam. The butterfly valve, like the automatic main throttle, is a final precaution against overspeeding and should only function in case the normal speed control devices fail.

A feature of the construction of the turbine rotor or spindle is the total absence of discs pressed or shrunk onto a shaft. All of the blade carrying elements are an integral part of the rotor, which is divided into longitudinal sections so that those blade sections requiring it may have a solid through disc construction without weakening holes. The various sections are provided with deep, flanged, pressed "spigot" fits, which allow them to be securely bolted after being pressed together, the bolting being on such a large diameter that the stress due to bending is negligible.

Where the turbine shaft passes through the ends of the cylinder a combined steam and water seal is provided to prevent the inward passage of air. As the turbine is double flow for the low-pressure portion, similar glands are required at each end. When standing by, or running at any speed below one-half of full turbine speed, the "labyrinth" type gland is sealed with steam, but on reaching about one-half speed a special governor in connection with a gland control valve turns the steam off and water on to the outer portion of the gland, which is provided with a form of paddle wheel or centrifugal pump runner. The water at a pressure of about seven pounds, is admitted to the runner chamber at the periphery, submerging the runner on each side a distance such that the centrifugal pumping head produced by the runner balances the total water pressure. Thus, as both sides of the runner are covered by water to a certain depth, no air can pass inward into the exhaust chamber of the turbines. The elimination of steam passing out from the glands in noticeable quantities, which is usually a feature of steam seals, is thus accomplished at practically all running speeds and relieves the engine room of what is often a very annoying feature.

As all of the operations of maneuvering are performed in the central control room, the speed of the main turbine is controlled from the same place. This is accomplished by the use of a variable speed governor, which regulates the admission of steam to the turbine, and by means of a power limit mechanism in connection with the governor-operated steam admission valve.

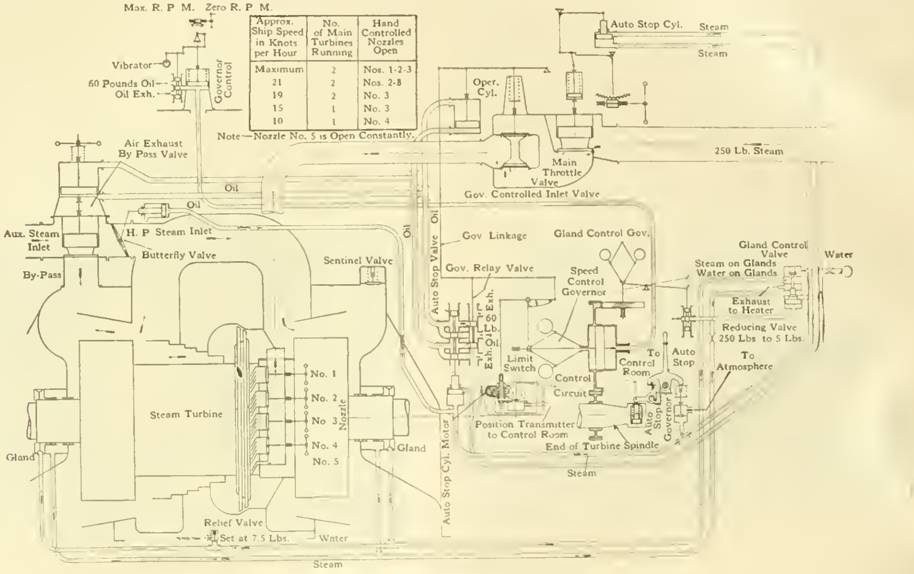

FIG. 3—SPEED AND POWER CONTROLLING MECHANISM

The governor tends to maintain a practically constant speed, irrespective of the load, corresponding to the setting of the speed control. The power limit is arranged so that the steam flow may be decreased, irrespective of the governor demands, but not increased beyond the amount needed to maintain the speed as determined by the latter. Fig. 3 is a diagram of the speed and power controlling mechanisms. Fig. 3 shows also the gland operating devices, which include a separate flyball governor with super-isochronous spring, driven by gearing from the main speed governor. This governor is set to move at about one-half speed, operating a steam relay which shifts the gland supply from steam to water and vice-versa.

The speed control governor, Fig. 6, is in principle a dead-weight fly-ball governor in which variable speed control is obtained by varying the dead weight. To do this, the effect of gravity in the ordinary construction is replaced by the pressure from a hydraulic piston

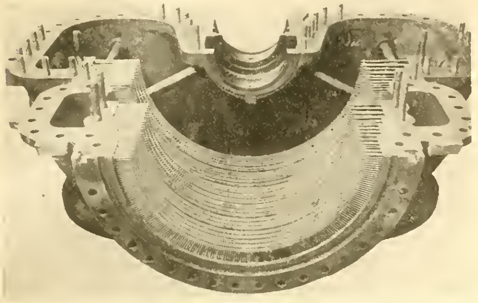

FIG. 4—ONE OF THE TWO SIMILAR CAST IRON LOW PRESSURE ENDS OF THE MAIN TURBINE

With the reaction blading of the lower half of the cylinder.

against which oil pressure of any desired amount from zero to 60 lbs. per square inch may be maintained. Thus, if the pressure is five pounds per square inch, the centrifugal force due to a turbine speed of about 400 r.p.m. will balance the piston, but if the pressure is increased to 55 lbs. the turbine speed necessary will be about 2100 r.p.m.

The oil pressure is regulated in the control room by the "governor control valve", Fig. 7. This is a piston opposed by a spring and supplied with oil through a relay plunger and floating lever arrangement. A constant source of oil under not less than the maximum

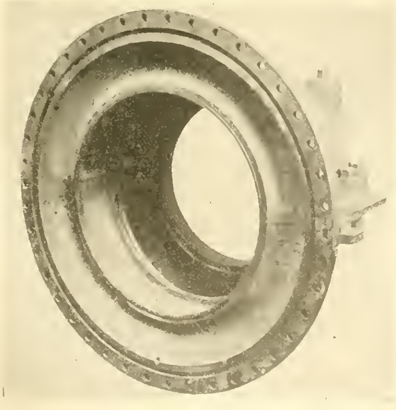

FIG. 5—CENTER SECTION OF TURBINE CYLINDER

This section being subjected to higher steam pressures and temperatures is made of cast steel and is bolted between the cast iron ends.

pressure desired is connected to the stand. On moving one end of the floating lever to a desired position, by means of a worm gear, the plunger is first moved so as to regulate the supply of oil under the piston, which in turn moves until the oil pressure balances the spring pressure. The floating lever automatically moves the plunger back to its neutral position, or that where the oil passed by it just equals the leakage from the system. Thus, for any position of the end of the floating lever, there is a definite position of the control piston and compression of the spring, with a corresponding oil pressure. The oil pressure, in turn, determines the speed of governing, so that for every position of the control wheel the main turbine will govern at the related speed. A motor driven vibrator moves the plunger up and down continually at about 160 times per minute. This serves to keep the oil pressure fluctuating slightly, enhancing the sensitiveness of the control.

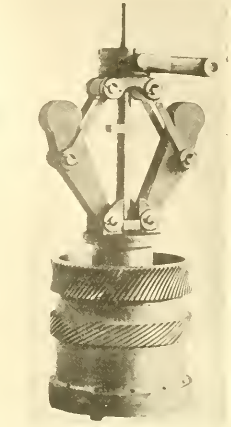

FIG. 6—SPEED CONTROL GOVERNOR

The governor operates the main steam admission valve through an oil relay system similar to that now generally used on the larger land turbines. Hand-controlled nozzle groups allow proportioning of the nozzle area to the load to be carried, and thus limit the demands on the boilers, as well as permit a proper choice of nozzles from the efficiency standpoint.

Exhaust steam from the auxiliaries is admitted to the low-pressure end of the main turbines. A by-pass

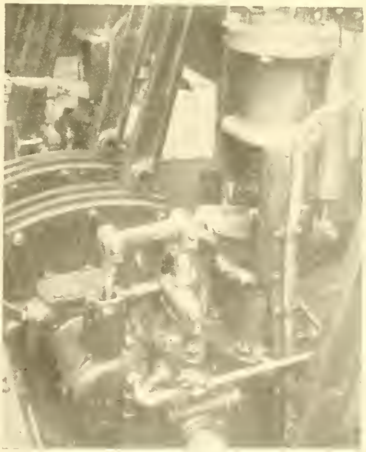

FIG. 7—GOVERNOR CONTROL VALVE

Located in the control room, it regulates the oil pressure for varying the dead weight of the speed control governor.

valve from this inlet to the exhaust of the turbine is opened either by hand or automatically by the oil relay system which controls the main steam admission valve, when this valve reaches its seat and there is sufficient

exhaust steam to cause the turbine to continue to speed up.

The turbine is started up and shut down by means of a hand-operated throttle valve in the main steam line. This valve is also connected through a steam-operated trip gear to a separate overspeed governor carried directly on the main turbine shaft. The same governor, with a similar mechanism, also shifts the oil supply to the speed control governor system lines, closing the main steam inlet valve and opening the auxiliary exhaust by-pass valve described above. It also causes the closing of a butterfly valve in the auxiliary exhaust inlet.

The bell crank connecting the main speed governor to the floating lever of the steam valve control, is made in two parts, held together as one by a suitable spring. A link from the floating lever connection engages at its lower end with the power limit in such a manner as to be free always to move downward, but only upward as far as the limit will permit. Thus the governor can always move its end of the floating lever so as to shut off steam, but can only move it in the direction of admitting more steam as determined by the power limit. The two parts of the bell crank separate, allowing the governor to move freely, but with the spring holding the floating lever against the restraining shoulder of the power limit.

This restraining mechanism of the power limit is moved to any position by means of a motor-driven worm gear. At the same time this gear is moving the limit, it revolves the transmitter of an electrical position indicator, the receiver of which is in the control room. It also operates a double stop switch, which breaks the motor circuit when the limit reaches either end of its travel, but does not prevent the motor being operated in the opposite direction. The control of this limit is, of course, in the control room, where the operator, by observing the positive indicator, knows its setting at all times.

Signal lamps disclose the relative positions of the governor and the limit, i.e., as to whether the steam is under the control of the governor or is being restrained by the limit. A similar lamp signal indicates when the main throttle is closed or open.

A pressure operated interlock, preventing the opening or closing of the generator field switch, is connected to the oil line between the governor control stand and the governor. It is adjusted so as to liberate the field switch when the oil pressure is below a certain amount, necessitating the setting of the governor speed control at a low speed before maneuvering can be done.

The Main Generators of the U. S. S. Tennessee

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The electric propulsion of a ship involves the supply of power over a wide range of speed, torque, and terminal voltage for the generator. In the case of the *Tennessee*, this power is supplied from alternating-current generators to induction motors, which are connected to the propellers. It is necessary that the combination of generators and motors be considered together, and that the apparatus be so designed as to have the proper characteristics to give satisfactory performance as a single unit.

Any alternating-current generator at a constant speed and excitation, will give a terminal voltage which is dependent upon the value of the load which it is carrying, and also upon the power-factor of that load. Assuming that the power-factor could be held constant, there would correspond to a fixed excitation a curve between kv-a and current, the kv-a starting at zero and increasing with the current up to a maximum value, and then decreasing again to zero, the terminal voltage at the same time starting at a maximum and decreasing to zero. A family of curves between kv-a and current could be drawn, corresponding to other values of the power-factor.

An induction motor at constant frequency very nearly follows the law that for a change in voltage the torque developed will change in the ratio of the square of the voltage variation, and that the slip, power-factor and efficiency will keep the same values as for the original torque. Further, the efficiency and power-factor of the motor at different frequencies will remain the same for equal torques, provided that such torques correspond to equal fluxes, or, in other words, that the impressed voltage is varied directly as the frequency.

Since, for any given condition of load, the generator voltage is dependent directly upon the excitation, it is evident that proper control of the excitation is most important. If the excitation is too low for the load to be carried, the generator will drop the load. If, on the other hand, the excitation is maintained at too high a value, then the terminal voltage of the generator will also be too high, resulting in unnecessary iron losses in both generator and motor. This latter condition, therefore, results in operation at a reduced overall efficiency.

The above brief statements show at once that the rating of apparatus for a ship is somewhat indefinite, since, for a fixed load at a given speed, the voltage, current, kv-a, and the power-factor will all change with a change in excitation. The rating is, therefore, necessarily nominal, unless it is tied up with a margin be-

tween working torque and maximum torque. The factors which determine the margin necessary in operation are the condition of the sea, that is, whether

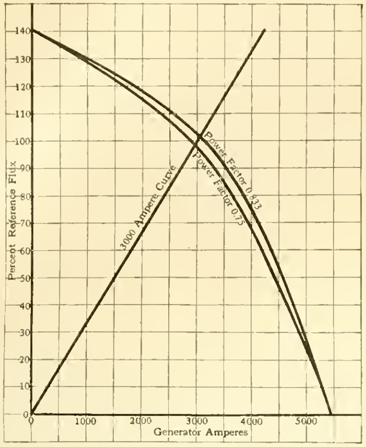


FIG. 1—GENERATOR VOLTAGE CHARACTERISTIC
The voltage, at any speed is proportional to the flux at 230 amperes field current.

smooth or rough, the loading of the ship and the setting of the throttle to limit the maximum power which can be delivered. In general, the margin of excitation at any time must be sufficient to prevent the motors be-

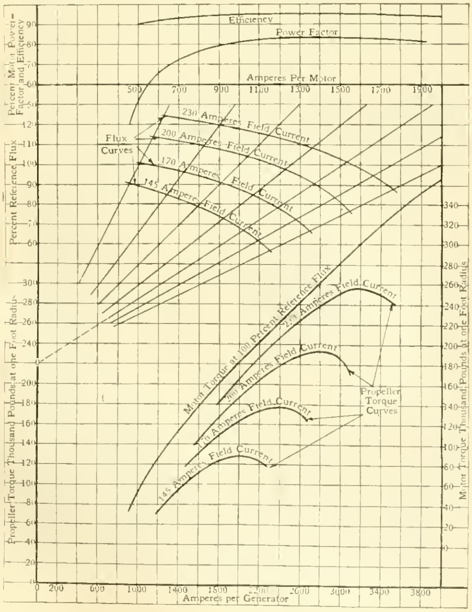


FIG. 2—COMBINED PERFORMANCE OF TWO MOTORS LOADED ON ONE GENERATOR

ing pulled out of step by any load within the limit of the throttle setting on the turbine. This is accomplished in practice through the adjustment of a stop on the throttle to limit its opening, and by setting the field current to the proper value. This value of field current is determined by means of the indication on the dial of an instrument which shows the relative value of working torque to maximum torque.

Inasmuch as the speed control of the ship is obtained by variations in speed of the turbine generators, which produce corresponding changes in generator voltage, it is obvious that there can be no fixed rated voltage or speed. The generator characteristic curves shown in Figs. 1, 2 and 3 are, therefore, plotted against what may be called a "reference flux," on the assumption that, with a given flux, the generator voltage is directly proportional to the speed, which is approximately correct. By reference flux is meant the flux corresponding to some arbitrarily chosen operating point. The variation of reference flux with current on the *Tennessee* generators under the condition of

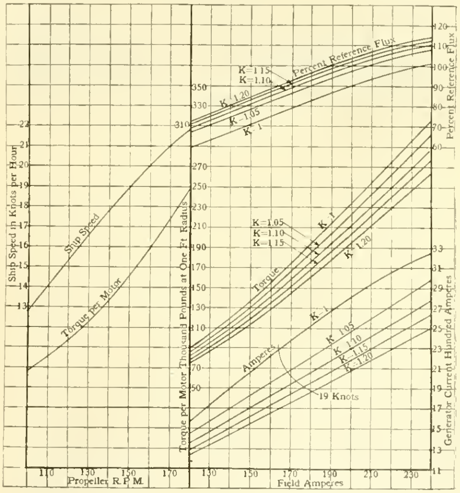


FIG. 3—STABILITY FACTORS, UNDER VARIOUS OPERATING CONDITIONS

constant excitation at 230 amperes field current is shown in Fig. 1. From a series of such curves taken in conjuction with the motor characteristics, the combined performance of two motors loaded on one generator is shown in Fig. 2 for several different values of field current. Fig. 2 gives the motor power-factor, efficiency and torque, as derived from test data, plotted against current. In addition it shows the generator current plotted against propeller torque for a series of field amperes on the generator. The construction of these points is as follows:

At 1500 amperes per motor (corresponding to 3000 amperes per generator, since the motors are in parallel), the power-factor, Fig. 2, is 0.833. In Fig. 1, a straight line is drawn from the zero point through the point corresponding to 3000 amperes and 100 percent flux. This "3000 ampere line" cuts the voltage

characteristics for 0.833 power-factor at 101.5 percent rated flux and 3060 amperes. This point is transferred to Fig. 2. Other points derived in the same manner from Fig. 1 give the characteristic curve for 230 amperes field current. The curves for the other

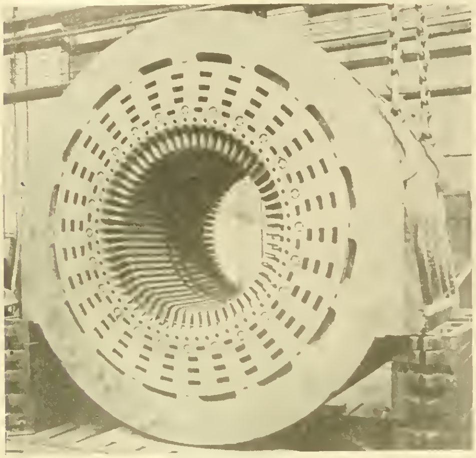


FIG. 4—STATOR CORE

field currents shown in Fig. 2 are similarly derived from other curves similar to Fig. 1 for the respective field currents.

The propeller torque curves corresponding to the various field currents in Fig. 2 are obtained from the flux curves and the motor torque curve, remembering that the torque relation varies as the square of the voltage change. Thus, for example, the motor torque at 100 percent flux and 1500 amperes per motor is 282 000 pounds feet. From the current flux curves for 230 amperes it is seen that at 3000 ampere load on the generator the flux is 1.02 times normal. This value squared, times the motor torque for 3000 amperes at 100 percent flux gives the actual propeller torque obtained with 230 amperes field current and 3000 amperes generator current, giving one point on the propeller torque curve, for 230 amperes field current. The other points on these curves are plotted similarly.

From Fig. 2 the curves in Fig. 3 are readily obtained. The values of K in Fig. 3 are stability factors, that is K equals the ratio between the maximum power which the generator can carry, and the total power required by the ship at any speed. The values for $K=1$ are taken from the peaks of the propeller torque curves, the four peak points in Fig. 2 giving four points on the torque curve for $K=1$ in Fig. 3. At any value of field current, the torque at 1.05 stability factor, equals that at unity divided by 1.05, etc.

Similarly the ampere curve for $K=1$ in Fig. 3 is obtained from the peak points of the propeller torque curves in Fig. 2, the ampere curve for $K=1.05$ is obtained from the $K=1.05$ torque points previously plotted on the propeller torque curves, etc. Likewise the reference flux-curves in Fig. 3 are obtained by drawing a vertical line from the corresponding points on the propeller torque curves in Fig. 2, from which the percent reference flux for each field current and stability factor are read.

Fig. 3 shows at a glance the stability factor corresponding to any given excitation for any speed of the ship, as well as the current and percent reference flux corresponding to the same conditions. For any given power, the change in excitation can be shown for different values of K. This has been illustrated on Fig. 3. for a speed of 19 knots.

GENERATOR EQUIPMENT FOR THE TENNESSEE

There are two generators on the *Tennessee*, each having a nominal rating of 13 250 kv-a, three-phase, 34.6 cycles, 3270 volts at 83.4 percent power-factor, and a maximum rating of 14 850 kv-a, three-phase, at 2195 r.p.m. The generators are arranged to drive two motors each over a speed range of 1548 to 2195 r.p.m., corresponding to a variation in ship speed from 16.1 to 21.8 knots. One generator will handle four motors between 15 and 16.1 knots, with a change in speed varying between 1435 and 1548 r.p.m. the motors being operated with 24 poles. For lower speeds of the ship between 10 and 15 knots, one generator handles four motors, operating with 36-pole connection. The speed range of the generator under this condition is between the limits of 1430 and 2175 r.p.m.

The principal difference in the electrical design of generators for ship propulsion and for ordinary land service are the necessity of providing insulation to withstand salt air, and the provision of a greater degree of overload margin in the field design for ship

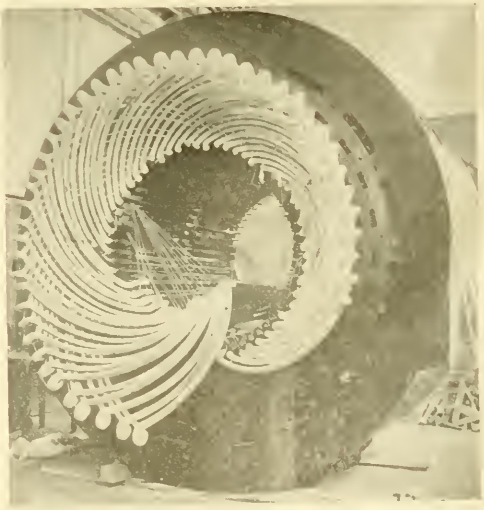


FIG. 5—STATOR CORE PARTLY WOUND

service. This overload margin must be provided to take care of short time operating periods, such as are encountered in turning, stopping and reversing the ship. The *Tennessee* generators are designed to withstand safely a 50 percent increase over their maximum continuous operating field current for short periods.

Temperature Rise—The generators are designed to deliver their rated output with a temperature performance in line with normal land practice. Tests made at zero power-factor show a rise by themo-couple of 53 degrees C. at a load of 13 500 kv-a, 36.5 cycles, 3460 volts, and 48 degrees C. at the same current, and at 10 800 kv-a and 28.8 cycles.

Mechanical Designs—The principal difference in the mechanical design as compared with land practice is the omission of the bedplate, and the addition of inlet and outlet dampers in the air ducts.

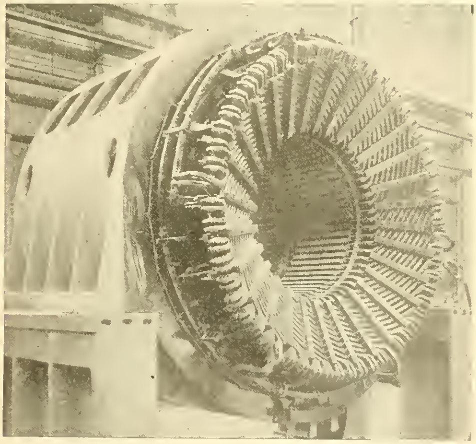


FIG. 6—STATOR COMPLETELY WOUND AND CONNECTED

Stator Core—The stator frame is an iron casting with inwardly projecting ribs. Into this frame are assembled the segments of sheet steel which made up the core. The ventilation is arranged for air to be passed in openings in the iron in an axial direction, and discharged at the center of the machine, as shown in Fig. 4.

Stator Windings—The stator winding consists of two conductors per slot; each conductor is, therefore, insulated from ground and from one another with a maximum factor of safety. Each conductor is made up of a number of strands, individually insulated with mica tape to break up eddy currents. The assembled strands are insulated on the straight part, which is buried in the core, with mica folium, and on the ends with mica tape. The end windings are then specially treated with a considerable number of coats of moisture resisting varnish to insure protection against salt in the cooling air. A core in the process of winding is illustrated in Fig. 5 Considerable care has been taken to brace the end windings as securely as possible. The finished stator winding is shown in Fig. 6.

Ventilation—The fans on each end of the rotor supply the cooling air. The air is drawn from a chamber under the end bells, and passes through the air-gap and axial ducts in the rotor and stator to the center of the machine. From there, it passes into the frame and out into the discharge duct. Dampers are provided in the inlet and outlet ducts to cut off the air supply when the ship is idle. Fig. 7 shows the inlet damper on one end, and shows the sheet metal casing connecting the generator with the discharge duct. The outlet dampers are mounted above this casing, and connect the generator outlet with the discharge duct in one limiting position, and in the other, connect the discharge duct directly with the engine room, at the same time closing off the generator outlet.

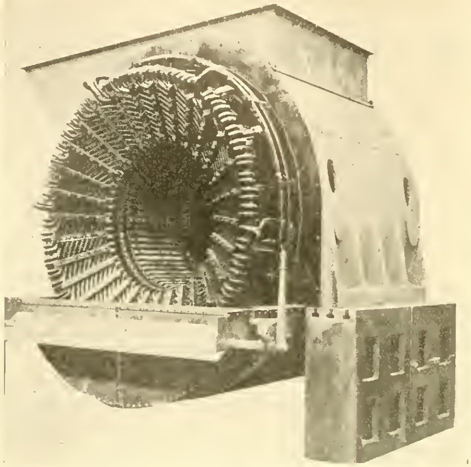


FIG. 7—DAMPER MOUNTED ON STATOR FRAME

Dampers are provided in the inlet and outlet ducts to cut off the air supply when the ship is idle.

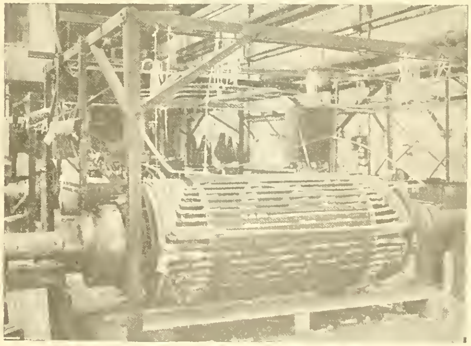


FIG. 8—ROTOR IN THE PROCESS OF WINDING

Rotor—The rotor is made of one-piece steel forg-

ing provided with radial slots which carry the coils. The windings are insulated throughout with mica or other fire-proof material. There is no provision for ventilation within the body, so that there is no chance of the accumulation of salt deposit in the rotor. Fig. 8 illustrates the rotor in the process of winding.

Steam Heater—To maintain the temperature of the generator above that of the surrounding air when the generator is idle, steam heating coils are provided in the end bell. This heater is necessary to prevent precipitation of moisture upon the coils and other parts of the machine where it might be objectionable.

The Nerve Center of the Battleship Tennessee

C. B. MILLS

Chief Engineer,
The Sperry Gyroscope Co.

In a modern battleship, such as the *Tennessee*, constructed for only one purpose and that to defeat the enemy, it is absolutely essential that the instruments of navigation and those by which the gun fire is controlled and directed be of the utmost accuracy and precision humanly possible, as the entire effectiveness of the ship and its excuse for existence is nullified unless she can hit the enemy ship aimed at.

On the rolling and heaving surface of the sea, a fixed and stable gun platform is impossible and the use of telescopic sights on the gun is no longer feasible at the ranges under which engagements now take

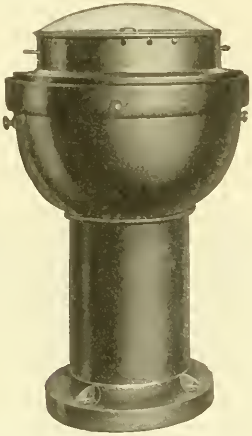


FIG. 1—SPERRY MASTER GYRO COMPASS
The two masters used on the *Tennessee* saw service on two United States Mine Layers in the North Sea during the war.

place. The need of a reliable means of controlling the ship's battery quickly and accurately from a single station has long been realized; in fact, present day methods of warfare have made such control absolutely imperative. Greatly increased battle ranges, interference of smoke, spray, and gases at the guns, inadequate means of concentrating the fire under adverse conditions, have been the chief causes leading to a centralization of control. At the same time, they have been determining factors in locating this control aloft.

To obtain maximum effectiveness the battery must be operated as a single unit. To this end there must be an accurate means of communicating to all guns the proper angles of elevation and train; the guns must be laid and the turrets trained to these angles; and finally, the whole battery must be fired from the central control, at the proper instant as determined by the officer responsible for the firing.

A naval engagement nowadays starts as soon as the enemy is sighted. With the long range turret guns now in use, firing begins immediately, often at 20 000 yards range, whether the enemy ship is in sight above the turrets' horizon or not. The only requirement is that it shall be visible from one of the fighting tops. It is apparent that under such conditions the ordinary telescopic sights in the turret are useless, and the ship that has no other method of sighting her battery,—

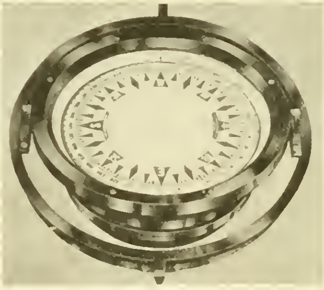


FIG. 2—GYRO COMPASS REPEATER
This repeater is controlled by the master gyro compass, through the panels shown in Fig. 3.

in other words, one not fitted with a central control aloft—is likely to be sunk long before she can close to a range where her guns can be used effectively.

It was to over-come these handicaps that the Sperry Fire Control System was devised in collaboration with the ordnance officers of the Navy, and is being fitted to all of our firstline battleships.

This system makes possible the control of all guns from the fighting top and the guns are trained, laid, and fired with the greatest accuracy under absolute control and with that co-ordination which insures the greatest damage to the enemy.

It will be obvious that however large a ship, it is still but a floating speck on the ocean, and that to fol-

low the enemy ship and maintain its proper bearing thereto a fixed base is absolutely essential. This fixed base line is provided by the spinning wheel of a gyroscopic compass which is located in the bowels of the ship, and which is not influenced in the slightest degree by the rolling and pitching of the ship, by magnetic influences, firing of salvos or any of the shocks, concussion, and tumult incidental to naval engagements. This spinning wheel is maintained in space, rigidly obeying nature's laws with its axis of spin pointing to the true north and lying in the geographic meridian.

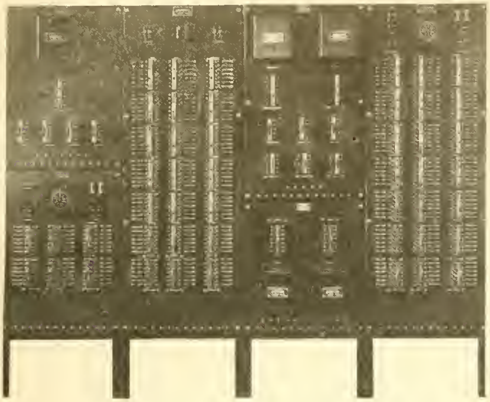


FIG. 3—RELAY SYNCHRONIZERS AND REPEATER PANELS

For the duplex gyro compass equipment aboard the *Tennessee*.

This so-called Master Compass may be called the master brain of the whole ship's intricate organization for navigation and fighting purposes, as on its integrity of action depends the entire effectiveness of gun firing. Continuous electrical impulses, synchronizing the repeaters with its own indicators, are sent out from it to all of the delicate ordnance instruments used in the various functions of training and laying of the guns, and to the various instruments by which torpedoes are aimed and fired. From this master compass emanate also circuits or nerve lines to the compass repeaters used for steering and taking bearings and the general navigation of the ship.

In the first-line battleships such as the *Tennessee*, these master compass equipments are always installed in duplicate, and under service conditions both are kept running continuously, so that in case of a break-down of any of the circuits due to gun fire, all of the compass repeaters and ordnance apparatus electrically connected thereto may be shifted over instantly to the remaining compass. This great responsibility resting on a small instrument has resulted in the development of a piece of mechanism which exhibits a refinement of workmanship, design, detail, and dependability placing it in a class entirely by itself.

It is a re-freshing thought, and one which is of supreme interest to the United States Navy, that this apparatus, mainly responsible for the fighting ship hitting the target, was the product of one of this country's well-known engineers and inventors and the best evidence of its undoubted fulfillment of purpose is the fact that of the United States first line of fighting ships, all use the gyroscopic compass as the foundation of their navigating and fire control equipment.

THE ELECTRIC JOURNAL	OPERATING DATA FOR CONVERTING SUBSTATIONS	JUNE 1921

Installation and Maintenance of Automatic Substations

Where the high-tension voltage justifies it, a completely new automatic substation, that is, one involving new apparatus throughout may be installed economically by making the arrangement include outdoor high-tension switchgear and transformers; the building being made to house only the rotating apparatus and the switching equipment for the low-tension side of the power transformers and the direct-current side of the machines. In single unit stations of 300 to 1500 kw capacity, the floor space required is relatively small in comparison with the ordinary manually-operated substations of equal capacity. Since outdoor high-tension apparatus is used, headroom for removing coils from the transformers is not required. The height of the building need then be only such as to permit of ready dis-assembling of the converting apparatus, in case it becomes necessary to make repairs. It is safe to say that this type of semi-outdoor construction eliminates from 25 to 50 percent of the building cost.

It has been argued that the alternating-current starting panel should be located between the transformers and the converter in order to economize in the cables connecting the transformers and the converter. However, the simplification of the control wiring and conduit layout made possible by assembling the panels in a composite group goes far toward offsetting any added cost of cable required for the main wiring between the panels, transformers and machines. Wiring diagrams and layouts showing the arrangement of conduits carrying the control wiring between various points in the substation, have been worked out for not more than six control wires in any one conduit. The control circuits are then wired with standard six conductor, rubber insulated, braid covered, flameproof cable. This permits the use of a standard six-hole porcelain covered terminal condulet, which makes it possible to bring the control wiring up to the terminals on the panels without cross wiring. The multiple conductor cable being coded, it is then possible, by lettering the conduits, to pick up the code at one end and immediately pick it up at the other, to trace any circuit. In the newer developments, sufficient space has been left and the panels used are large enough so that the wiring on the back of the panels is not crowded, thus making it possible to trace readily any circuit in the substation. This is of great importance, especially in starting up a new station, where it is necessary to check over the wiring to see that all circuits are in the proper condition. Also in locating any fault in the substation while in operation, this method of wiring proves of great benefit.

CONDUITS

For the small control wiring, it is common practice to use one inch conduit with standard fittings. Conduits for the

main power cables are to be chosen only after taking into consideration their location, that is, whether the conduits carrying them are to be run in the open, or buried in the earth or concrete floors. Metal conduits, when properly installed and protected against corrosion, have proven very satisfactory. Another good method of installing conduits underground is to use the standard fibre duct encased in concrete. Even should the fibre duct be destroyed by the action of moisture, the duct is left more or less intact in the form of the concrete shell. One of the most successful conduits used, both with lead covered and other cables, is the ordinary tile duct laid in concrete.

Lead covered cable, when properly installed and mechanically protected, makes up an excellent installation; however, in case the cable is damaged by handling, it sometimes happens that breakdowns of insulation occur and circuits thus set up between adjacent cables have resulted in considerable damage. It is the opinion of a number of companies that, for interior work where there is little or no moisture, the cost together with the installation expense of lead covered cable is not justified. In their opinion, the rubber insulated, flameproof, braid covered, cable is superior for this work. This type of cable also has an advantage in that it is more conveniently handled. Where leadcovered cable is used, care should be exercised in separating cables between which dangerous circuits may be set up due to failures of insulation, resulting from possible mechanical damage to the cable sheath and the insulation.

INSTALLATION OF AUTOMATIC SWITCHING IN OLD MANUALLY-OPERATED SUBSTATIONS

Very often new automatic switching equipment can be installed in present manually-operated substations by simply arranging the automatic panels to parallel with those of the present manually-controlled board. This, of course, is dependent wholly upon whether or not there is sufficient floor space. Often it is necessary to remove the manual switching equipment in order to make space for the new apparatus, in which case many of the old conduits may be utilized. It is always necessary, however, to install a very considerable amount of control wiring and this necessitates opening the floors to permit laying of conduits. It is not often that new conduit is required for the main power cables; however, if this is the case, it is generally more convenient and results in a much better installation if the old floor is removed and the conduits placed in position before the new floor is put down.

OPERATION

If the men who are to have the care of the substations are permitted to assist in the installation of the apparatus, it will obviously be of material benefit to them later in their operating duties. Once complete, the installation should be thoroughly inspected to see that all main wiring and control connections are properly made. It is preferable to use lock washers on all control wiring studs. All of the auxiliary contacts on the main contactor switches and the control relays should be inspected to make certain that the contacts are clean and contact pressures sufficient. Contactors operated with alternating current should be so adjusted as to prevent excessive vibration and noise. Complete inspection will prevent the unnecessary shutdowns, which always follow if this procedure is neglected.

INSPECTION

It is often said that even a wheelbarrow needs a certain amount of attention to keep it in good operating condition. The mere fact that a substation is made automatic does not mean that it will continue to function automatically without proper attention. By proper attention is meant periodic, thorough and intelligent inspection. A man may visit a substation every day and find it operating each time. For this reason he may feel satisfied that everything is in good condition. Often this is not the case, for it may be that the station is still operating in spite of some slight misadjustment. Sooner or later this condition is apt to cause a shutdown, whereas, if corrected at the proper inspection period, the failure would have been prevented. It is, therefore, of prime importance that the inspector be thorough and systematic in his care and maintenance of the equipment. A complete inspection once every other week or once each month is far better than a daily visit, solely for the purpose of learning whether or not the station is still in operation. The manufacturers are doing everything possible and adopting every improvement that will make the equipment as nearly as possible fault-proof; but only with the hearty co-operation of the operators can they hope to produce apparatus that will give the superior service, which is to be obtained from substations automatically controlled.

In a number of cases automatic equipments have been installed where they were the first of the kind to be put into operation for a particular service. In so far as possible, the manufacturer has made every effort to include, in the scheme of control, every protection and refinement of operation known to the art; however, conditions not anticipated may arise. A frank discussion of any of these points will prove very beneficial to both the manufacturer and the user. The success of automatic switching in any application is dependent upon the operator as well as the manufacturer. Close co-operation between all concerned, combined with proper care and maintainance not only of the switching equipment, but of the apparatus as a whole, are the elements which assure satisfaction.

The success and increasing popularity of automatic substation apparatus is shown by the fact that by far the greater percentage of new stations installed within the past few years are of this type. C. A. BUTCHER

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1986—RATIO OF FIELD TURNS AND ARMATURE TURNS—Can you give me the general relationship between the number of turns and size of wire on the armature and the number of turns and size of wire in the fields of shunt wound motors for a given speed and horse-power? (b) The same relation between the armature and field windings of a series motor for any given speed and horse-power? (c) The same relation between the armature and field windings (shunt, series and commutatingpole) on compound and compound-commutatingpole motors for any desired speed and horse-power? D. E. C. (PA.)

On constant speed motors, from 5 to 15 hp. the armature ampere-turns will average about 75 percent of the shunt and series ampere turns. On larger motors the armature ampere-turns may reach 95 percent of the shunt and series ampere-turns. On totally enclosed motors, the ratio of armature ampere-turns to shunt and series is smaller than for constant speed open motors. The current density in the shunt field is about 50 percent of the current density in the armature, while the current density in the series field is about 40 percent and in the auxiliary field 35 percent of the armature density. On a series motor the armature ampere-turns may be a slightly smaller percent of the field ampere-turns than in a shunt motor. The current density in the series field is about 35 percent of armature density. W. R. H.

1987—TRANSFORMER RATIO—Is there any simple method of determining whether any high-tension coil of a single-phase transformer is reversed when the ratio is so great that a suitable ratio check cannot be made with the available voltage and voltmeters at hand, as in the case of transformers of the type used on furnace work, stepping down from about 60 000 to 60 volts. C. S. (QUEBEC)

Where no special apparatus is available, the most convenient method to determine if any high-voltage coil is reversed, is to connect a suitable low voltage across the high-voltage winding. With one lead of a voltmeter permanently connected to one of the coils, measure the increase in voltage when moving the other voltmeter lead from one coil to the next. In case one coil is reversed a decrease in voltage would be observed when passing this coil. H. F.

The Electric Journal

Vol. XVIII — July, 1921 — No. 7

Stray Losses in Converters

When the Standards of the A. I. E. E. were revised in 1913-14, considerable test information was presented to the Standards Committee showing the magnitude of stray losses in alternating-current generators and motors, and definite rules were adopted governing the inclusion of stray losses in the conventional efficiency. No data, however, was available concerning stray losses in synchronous converters and the Standards of the Institute have never specified the magnitude of the stray losses nor included them in the conventional efficiency for this class of machinery.

During the past few years the effect of stray losses on the efficiency of large 60 cycle booster converters has been questioned in several instances on account of low efficiencies obtained by input-output tests made after installation. More recently the booster converter has been charged with low efficiency as compared with the simple converter without booster, presumably because of increased stray losses.

On account of these unsettled questions the information contained in Mr. Hague's article on "Stray Losses in Synchronous Converters" is timely and instructive. Such tests as he describes are difficult to make, but the care as to details in this case has made possible results that are unusually consistent. Tests of this character are strictly laboratory tests, are expensive (costing several thousand dollars in the case of a large unit), tie up considerable equipment and are justified only when the results are generally applicable.

Mr. Hague's curves show that the stray losses for the several voltage conditions, and the same load, do not differ greatly. This small variation disposes of the supposition that the efficiency of the booster converter is much lower than that of the simple converter because of greatly increased load losses when the booster is excited.

Another interesting point is the effect of low power-factor operation on the stray losses and on the efficiency. The tests show a greater stray loss in the simple converter, with a variation in power-factor sufficient to obtain a five percent change in voltage, than in a booster converter designed to give a twelve percent variation in voltage.

An important fact brought out is the large variation in the stray losses with greater loads than normal. This is, of course, well known and characteristic of stray losses generally that are dependent on current. Under all voltage conditions, the stray losses increase about 50 percent with a 25 percent increase in load above rated load. While the conventional efficiency continues to increase at loads in excess of rated, the actual efficiency is maximum at rated load and falls off apprecia'y at larger loads. The converter used for these tests was designed for nominal and overload rating. When converters are designed for the single rating (without overload) the copper and brush current densities cannot be increased appreciably above those that have been employed at the nominal continuous rating in the older designs without a real sacrifice in the true efficiency.

F. D. Newbury

Power Transmission

No matter how simple the problem, any transmission system is more or less complex in that it must necessarily include step-up and step-down transformers and secondary distribution systems besides the relatively simple transmission line itself. Each of these component parts has its own individual effect upon the regulation, power-factor, and transmission efficiency. This being the case, the process of calculation is necessarily complicated if the problem is to be solved so as to point out the most economical case. The usual method is to rely upon the experience of the individual engineer, in making approximations for a complete solution. To determine the most economical combination of the numerous factors involved it is usually necessary to make several complete solutions based on different assumptions and compare the cost of each so that any means used to simplify the calculations without sacrificing accuracy are quite desirable.

Simplified methods of making such computations have recently been worked out by Messrs. Evans and Sels, and the first of several articles, which cover the best of the present day methods of calculations for transmission problems in their entirety, appears in this issue. While these computations may appear complicated, they work out quite simply and possess several advantages over more approximate methods. The methods need not be strictly mathematical but can be applied graphically. They provide quite a simplification, as they treat a given transmission problem as a network, deriving general circuit constants for the whole. In general these constants will remain unchanged and are exact for any operating condition and may be used either mathematically or graphically in solving different load conditions.

The articles are general but, whenever possible, simplifications have been pointed out which will involve little approximation. When the computations are made in an orderly manner according to some standardized form, quite a saving in time is obtained without any serious approximations, as the general formulas for the constants are quite exact and in no case involve the difference of two large quantities. This fact enables anyone to follow the methods outlined easily and to obtain an economical as well as accurate solution of any problem.

F. C. Hanker

Stray Losses in 60-Cycle Synchronous Booster Converters

Determination by Input-Output Tests

F. T. HAGUE
Power Engineering Dept.,
Westinghouse Electric & Mfg. Company

THE stray losses in synchronous converters have never received as much consideration as the stray losses in other sources of direct-current power supply, due to theoretical considerations and actual tests which show these stray losses to be quite low in comparison with those in other forms of conversion apparatus. The statement has recently been made that the stray losses in the booster type converter are materially higher than the stray losses in the simple converter, the difference in efficiency being claimed to be as much as two or three percent. The actual determination of operating efficiency and stray losses under various conditions of operation, by means of laboratory input-output tests, appears to be essential at infrequent intervals in order to direct attention to and maintain the true relative status of the losses in the various types of synchronous converters.

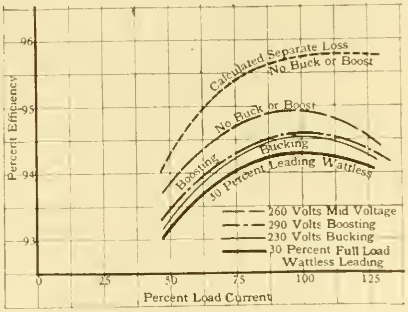


FIG. 1—INPUT-OUTPUT EFFICIENCY TEST

On 6 000 ampere, 290—260—230 volt, 60 cycle synchronous booster converter.

The stray losses of a 6000 ampere, 60 cycle, synchronous booster converter were determined by taking the difference between the efficiency by the separate loss method and the efficiency by laboratory input-output tests. The machine used was a 6000 ampere, 60 cycle, 260 volt, booster converter having a voltage range of 230 to 290 volts. The unit is large enough to be typical of those used in Edison service without being too large for careful factory testing. The input-output test methods used, while not new, comprised all of the details and refinements in equipment, methods and personnel that have been found to be essential in tests of this character. The alternating-current power was measured by three single-phase wattmeters and also by one polyphase wattmeter while the direct-current power was measured by two sets of direct-current volt-meters and ammeters with independent shunts. A trained force of meter readers was used, and all meters were thoroughly shielded. Four groups of 15 readings each were taken for each load, each group with different meter positions, and different meter readers; special precautions were taken to avoid including any readings during which change of load occurred. Tests of this character are strictly laboratory tests, costing from one to two dollars per machine kw in addition to tying up much testing equipment. Although not feasible on commercial circuits, laboratory input-output tests are justified on the manufacturer's part when they represent the only method whereby comparative data can be obtained on certain operating conditions.

TABLE I—EFFICIENCIES AND PERCENT STRAY LOSSES FOR VARIOUS LOADS AT UNITY POWER-FACTOR

Load in Amperes	3000	4500	6000	7500
Load in Percent	50	75	100	125
260 Volts, No Buck or Boost				
Separate Loss Efficiency	94.25	95.40	95.75	95.80
Input-Output Efficiency	93.85	94.65	94.95	94.55
Percent Stray Loss	0.40	0.75	0.80	1.25
230 Volts, Bucking 30 Volts				
Separate Loss Efficiency	93.45	94.70	95.25	95.35
Input-Output Efficiency	93.30	94.25	94.55	94.25
Percent Stray Loss	0.15	0.45	0.70	1.10
290 Volts, Boosting 30 Volts				
Separate Loss Efficiency	93.80	95.10	95.55	95.65
Input-Output Efficiency	93.40	94.30	94.60	94.35
Percent Stray Loss	0.40	0.80	0.95	1.30
260 Volts, 30 Percent Full Load Leading Wattless				
Separate Loss Efficiency	93.70	95.10	95.60	95.70
Input-Output Efficiency	93.20	94.05	94.30	94.10
Percent Stray Loss	0.50	1.05	1.30	1.60

Input-output tests at 100 percent power-factor on converter collector rings were made at 50, 75, 100 and 125 percent loads for the following four operating conditions:—

1—No buck or boost 260 volts
2—Boosting 30 volts to 290 volts
3—Bucking 30 volts to 230 volts
4—No buck or boost, with 30 percent of full load leading wattless current at the converted terminals.

The stray losses may be summarized for these four conditions of operation as shown in Table II.

The magnitude of the individual losses at full load for each of the above conditions of operation are shown in Table III. In all segregations of losses

the individual losses are expressed in percentage of the converter input.

With accurate data on the magnitude of stray losses in a converter armature when working at maximum boost voltage and when working at 30 percent full load wattless current, it is possible to make an accurate efficiency comparison between the booster type converter and the simple converter whose voltage range is obtained by drawing wattless currents through

TABLE II—SUMMARIZED STRAY LOSSES EXPRESSED IN PERCENT

Percent Doad	50	75	100	125
Mid-Voltage	0.40	0.75	0.80	1.25
Bucking 30 Volts	0.15	0.45	0.70	1.10
Boosting 30 Volts	0.40	0.80	0.95	1.30
30 Percent Full Load Wattless	0.50	1.05	1.30	1.60

an external reactance. This comparison is not, however, on machines designed for the same voltage range, the booster type having the usual twelve percent range, while the reactance control unit has a five percent range corresponding to 30 percent full load wattless current in the converter armature. The stray losses as determined with 30 percent wattless current in the booster type unit must be modified by subtracting the stray loss in the booster itself. The booster is merely an alternating-current generator of high standard performance characteristics, having about three percent reactance, and its load loss, like other 60 cycle generators, should be 0.7 percent of its rating. In terms of the converter kw its load loss would be 0.7 percent $\times$ 0.12 percent = 0.084 percent. It should be fair to assume 0.10 percent as a maximum value for this booster stray loss reducing the stray loss of the reactance control unit from 1.3 percent to 1.2 percent. A comparison of the segregated losses and efficiencies at full load would then be as shown in Table IV.

TABLE III—PERCENTAGES OF INDIVIDUAL LOSSES

Converter Output Kw. / Machine Element	Mid-Voltage 1560 Kw	Buck 30 Volts 1380 Kw	Boost 30 Volt 1740 Kw	30 Percent Wattless 1560 Kw.
Friction & Windage	0.86	0.97	0.77	0.86
Brush Friction	0.61	0.69	0.54	0.61
Rotary Shunt Field	0.22	0.20	0.28	0.25
Booster Shunt Field	0.00	0.10	0.08	0.00
A. C. Brush C^2R	0.25	0.28	0.22	0.25
Series Com.Wdg C^2R	0.23	0.26	0.20	0.23
Rotary Core Loss	0.83	0.73	0.93	0.83
Booster Core Loss	0.00	0.21	0.16	0.00
Rotary Arm. C^2R	0.52	0.55	0.59	0.64
Booster Arm. C^2R	0.23	0.21	0.26	0.26
D. C. Brush C^2R	0.49	0.55	0.44	0.49
Stray Loss	0.80	0.70	0.95	1.30
Total Percent Loss	5.05	5.45	5.40	5.70
Full Load Efficiency	94.95	94.55	94.60	94.30

In summarizing the foregoing data it is interesting to note that the full load efficiency of the booster type converter, even on 60 cycles, does not vary more than 0.40 percent between its mid-voltage and its extremes of buck and boost and at half load the variation in efficiency is only 0.55 percent. On 25 cycle units the magnitude of the stray losses would be materially less. The stray loss of 0.80 percent at mid voltage, 0.70 percent at maximum buck and 0.95 percent at maximum boost further emphasizes that the 60 cycle booster converter obtains its wide flexibility in voltage range and other desirable operating characteristic with no sacrifice in economy of operation. The dis-

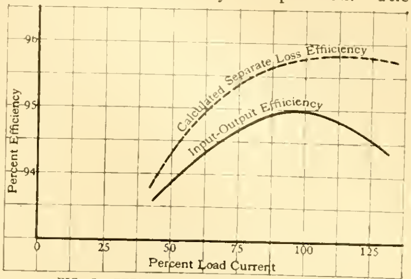


FIG. 2—EFFICIENCY TESTS AT 260 VOLTS

proportionate increase in stray losses above full load current, that is characteristic of all stray losses is valuable data when considering the advisability of increasing the continuous rating to a "maximum" rating on converters without making changes in the converter design to keep the current densities at low established values in those parts subject to stray losses, particularly the brush densities. The comparative data showing the efficiency and stray losses when working with appreciable wattless currents illustrate that such operation is obtained at a material reduction in efficiency and increase in stray losses. The converter is essentially a unity power-factor machine and, if its efficiency possibilities are to be fully realized and its operating maintenance kept within low limits, it should be so operated. The comparison of efficiency between the booster and reactance control types merely confirms previous experience with the losses in converters

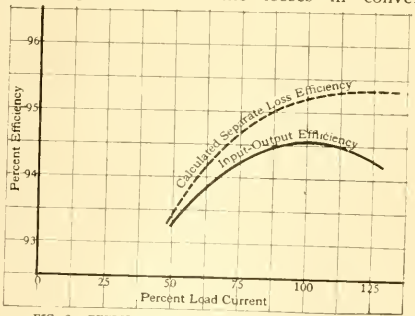


FIG. 3—EFFICIENCY TESTS BUCKING TO 230 VOLTS

worked at low power-factor. The machine efficiencies at most do not differ by more than a few tenths of one percent at full load, while if the total losses are summed up in the transformers, transmission lines and power house generating apparatus due to the low power-factor operation, the comparison will be on an equitable basis and permit a decision based on all of the facts.

DISCUSSION OF STRAY LOSSES

In forming a conception of the possible magnitude of stray losses and the differences in efficiency of slightly different types of machines based on test results, it is helpful to keep in mind the logicat magnitude that such losses or differences might assume without indicating unreliable or unavoidable errors in testing. In the converter armature itself, it is seldom appreciated what a large percentage of the full load losses are constant in magnitude and not subject to stray losses. Referring to the losses in Table III, the first six losses are not subject to load loss, while the latter five are. Out of 5.05 percent total loss on this 60-cycle converter there is only 2.07 percent subject to stray loss so that the measured stray loss of 0.80 percent at mid voltage represents an increase of 38 percent in the total losses represented by the sum of iron, copper and direct-current brush losses.

Stray losses are incident to the losses in three separate parts of a converter:—(1) the armature iron;

TABLE IV—PERCENTAGE OF THE SEGREGATED LOSSES AND EFFIENCIES

Items	Booster Converter 12% (30 V) Boost 1740 kw	Reactance Control Converter 5% (15 V) Boost 1640 kw
Machine Element		
Friction and Windage	0.77	0.64
Brush Friction	0.54	0.57
Rotary Shunt Field	0.28	0.25
Booster Shunt Field	0.08	0.00
A. C. Brush C^2R	0.22	0.24
Series Comm. Winding C^2R	0.20	0.22
Rotary Core Loss	0.93	0.87
Booster Core Loss	0.16	0.00
Rotary Arm. C^2R	0.59	0.61
Booster Arm. C^2R	0.26	0.00
D. C. Brush C^2R	0.44	0.47
Stray Loss	0.95	1.20
Total Loss	5.40	5.07
Efficiency	94.60	94.93

(2) the armature copper; and (3) the direct-current brush C^2R. Stray losses in the armature iron are caused by increased magnetic densities due to the action of the load current. The booster converter at mid-voltage has an armature reaction or field flux distortion of only 10 percent as great a magnitude as an alternating-currrent generator at unity power-factor, due to the fact that the individual alternating-current and direct-current reactions almost completely oppose each other. At 15 percent boost the converter armature distortion is increased to 25 percent and at 15 percent buck is reduced to five percent of the corresponding alternating current generator values. From this knowledge of the internal flux relationships, it is evident that the stray iron losses of a converter are materially less than those of a corresponding size alternating current generator.

The increase of armature copper loss due to bucking or boosting is readily obtained from a consideration of the theoretical relationships of the converter armature currents and, being subject to calculation, is included among the measurable losses. The magnitude of the eddy current losses in the armature conductors may be calculated with fair accuracy, as is done on alternating current generators, or may be estimated on a comparative basis by comparing the armature conductor and slot proportions with those

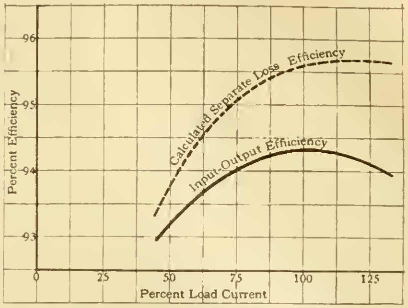


FIG. 4—EFFICIENCY TESTS BOOSTING TO 290 VOLTS

used in alternating current generator practice. Due to the opposition of the alternating and direct currents in the armature winding the copper loss of a six-phase converter at mid-voltage is less than 30 percent of that of the same machine as an alternating current generator, and correspondingly there is only about 33 percent of the copper volume available to be subject to eddy losses. The converter armature slot proportions are again much more favorable from the eddy current standpoint than those of the alternating current machine.

The direct-current brush C^2R loss is primarily a matter of design proportions and commutating reactance voltage and secondarily a matter of commutating pole adjustment. The stray loss in this connection is caused by the local or short-circuit currents set up in the brush face and the commutated armature coils during commutation, and may amount to an unexpectedly large magnitude. Experience has shown the use of direct-current brush densities materially in excess of 50 amperes per square inch on 60 cycle units and

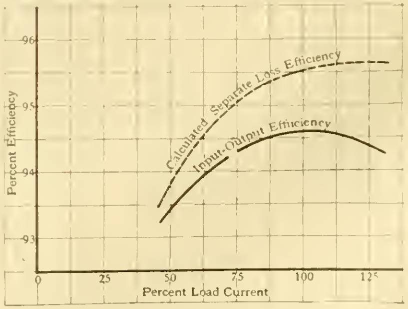


FIG. 5—EFFICIENCY TEST AT MID VOLTAGE WITH 30 PERCENT WATTLESS LEADING CURRENT

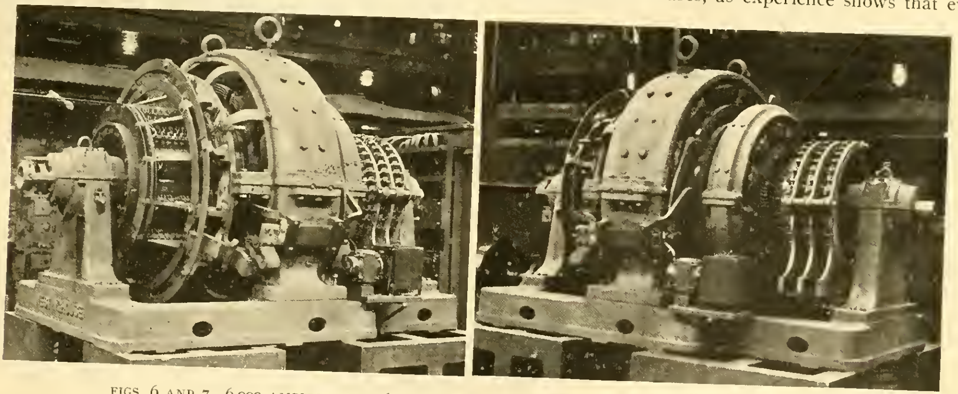
60 amperes per square inch on 25 cycle units, resulting in large normal brush losses and brush stray losses and has a most important influence on commutator and brush maintenance expense. The best assurance of low brush stray loss is obtained by designing a convert-

er of low commutating reactance and small brush short-circuit currents, which condition is obtained in modern converter design by using the minimum number of commutator bars per pole that is safe from the flashing standpoint. Modern 250 volt converters using 18 bars per pole on 60 cycle and 21 bars per pole on 25 cycles possess commutating and performance characteristic well worthy of the high standard of Edison service, and while somewhat more expensive than the older units using higher numbers of commutator bars per pole, they have a minimum of stray losses and give a materially reduced brush maintenance expense.

COMMENTS ON INPUT-OUTPUT TESTS

The determination of the actual operating efficiency by means of input-output tests is by no means the simple matter it may appear to the uninitiated. The merits and demerits of this type of testing were thoroughly reviewed in A. I. E. E. papers in 1913 the most optimistic claim for its accuracy, under ideal laboratory conditions was a plus or minus range of 0.2 percent while the general concensus of opinion favored a range of considerably more than this value. The general theory of the test is simple enough it being necessary merely to obtain simultaneous readings of three single-phase wattmeters and the direct current and voltage. The percentage accuracy obtainable is dependent primarily upon the magnitude of the loss which it is desired to determine in comparison with the total quantity of power which must be measured in order to determine it. The converter, with its low percentage loss, is the most difficult type of unit on which to make accurate input-output tests, as two quantities of the magnitude of 100 (total power) must be measured in order to determine a quantity of the magnitude of five (losses). There are four important sources of error:—(1) Accuracy and constancy of meters; (2) Reading errors of observers; (3) The load variation or swinging, that is inevitable on all commercial circuits and which is almost impossible to eliminate even on laboratory tests; and (4) The constancy of the machine's no-load losses.

Meter Errors—The direct-current meters may readily be checked before and after tests and there is more likelihood of error due to the selection of type of meter (undampt type is preferable) and careless leveling and handling, than in variation of calibration constants. The ammeter shunts used in factory laboratory tests may be calibrated, but once installed in a power company's bus-bars, these shunts represent an unknown magnitude of error. An expedient used in these particular tests for the purpose of further eliminating errors was the use of entirely independent, duplicate sets of meters and shunts. The external magnetic fields set up by large current machines or the proximity of heavy power circuits must be completely neutralized before accurate metering is possible. It is always essential to select a location for the meter tables where the stray magnetic fields are weakest. Shielding of meters by enclosing them in steel cages, whose only opening is a slot for reading the meter scale is essential in all cases, as experience shows that even complete shielding is not absolute protection against stray magnetic fields. The steel shielding cages, while affording considerable protection from external fields, also put the meter off normal adjustment, due to the steel sides acting as magnetic shunts to the permanent magnets of the meters. The meter should be kept at least two inches from walls of the shielding cage by being firmly wedged in place by wooden blocks, as even under these conditions the meter reading is effected more than 0.5 percent by the shunting effect of the steel cage. It is unnecessary to point out the necessity of calibrating the meters under the conditions of the actual test.



FIGS. 6 AND 7—6 000 AMPERE, 290—260—230 VOLT, 60 CYCLE SYNCHRONOUS BOOSTER CONVERTER

Observation Errors—Accuracy in simultaneous readings is impossible without preliminary training of a carefully selected crew under actual testing conditions. Care in selection of testors is equally important as in calibrating meters because the test results are no more dependable than the most inefficient meter reader. Even the most carefully selected meter readers have a personal correction

factor which cannot be eliminated, but which can be averaged by rotation of meter readers to a different set of meters at each group of readings. The rotation of meter readers is usually avoided because it necessitates a rather long period of training to familiarize the men with all of the meters. Speed and accuracy, however, are not synonymous on input-output tests where consistency is required. Even with shielded meters it is desirable to take four groups of readings with all meters rotated 90 degrees for each group so that all combinations of stray fields and meter illumination are averaged for the four compass positions.

Fluctuating Load Errors—No commercial load is absolutely steady and the nearest approach to this ideal is obtained in laboratory tests by loading the machine wholly or partly on a resistance load. Most commercial single-phase wattmeters are considerably less damped than the direct-current ammeters and voltmeters, resulting in the alternating-current and direct-current meters swinging unsynchronously with changes in load or in supply voltage. This load swinging, when infrequent, may be minimized in effect by an additional undamped alternating-current meter to indicate those readings taken during a change in load. It is customary to take ten consecutive simultaneous reading of all meters at ten second intervals; however, in these tests 15 readings were taken and the five readings corresponding to any load change as shown on the undamped meter were discarded, leaving ten readings under steady load conditions.

Single-Phase Polyphase Wattmeters—The use of three single-phase wattmeters is preferred over a polyphase indicating meter, partly because the single-phase meters are not readily subject to improper connections, and chiefly because experience with the two types on the same tests leaves one more favorably impressed with the consistency and accuracy of the single-phase method. On the basis of probability of error, the use of three meters is preferable to one meter, as any slight error on single phase is averaged between three meters and has a fair chance of being neutralized by the readings of the two other observers.

The polyphase wattmeter, consisting of two current and voltage elements transmitting their torque to a common shaft, is readily subject to errors in connection on the six-phase diametrical circuits used on converters. With absolutely balanced low tension converter currents there are two voltage connections which give correct results, but with the unbalance of low-tension current that is common to heavy current converters due to unavoidable inequalitties of low tension lead reactance, there is only one correct connection, the other possible connection giving errors of the magnitude of two percent plus or minus on converters with slightly unbalanced low-tension current.

The Automatic Electric Bake Oven

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DURING the last decade industry after industry and process after process has been electrified and yet the baking industry, one of the oldest in the world, is among the last to take advantage of the inherent qualities of electric heat. Bread baking has gradually grown into one of the largest industries in existence. Evolution and the centralizing of population in the cities gradually demanded larger equipment and better methods of baking bread scientifically and in large quantities. To meet these conditions a constant, uniform temperature in the baking chamber is of fundamental importance.

In early methods of baking practically no attention was given to the uniformity of heat during the bake. The principal object was to have the oven at approximately the baking temperature at the beginning of the bake but no means were provided to hold this temperature for any length of time. Only within the past fifteen years has any real persistent engineering effort been made to establish the baking industry with ovens of modern types and designs, and even today we find in many of the large as well as the small bakeries, the old brick "kiln type" oven. These ovens are nearly all gas or coal fired and represent practically no advance in this art for generations past.

Perhaps the most important step forward was taken when gas ovens of the "ferris wheel type" were brought out. These ovens, while not entirely satisfactory for a number of reasons, represented a great advance, for the rotation of the bread in the baking chamber insured having each tray pass successively through the same temperature zones, which means that every loaf will bake uniformly and brown evenly all over. Even baking and browning of the bread requires that the oven be heated uniformly from end to end of the baking chamber, for if one is hotter than the other, the bread will bake faster at that end, necessitating either unloading the oven one end at a time or over browning the loaves on the hot end. However, all the loaves on each end will be at the same degree of brownness. Uneven temperature in the two ends of the oven has been a source of great trouble in gas-fired ovens, requiring constant attention and manipulation of the gas burners. Also gas ovens are rarely provided with any sort of heat insulation, thus being quite uneconomical as well as disagreeable to work with, and even danger-

ous as a fire hazard. Also gas ovens do not have automatic temperature control, resulting in poorer quality of bread and increased labor costs, due to the greater attention required for each oven.

Recognizing the superiority of the general principle

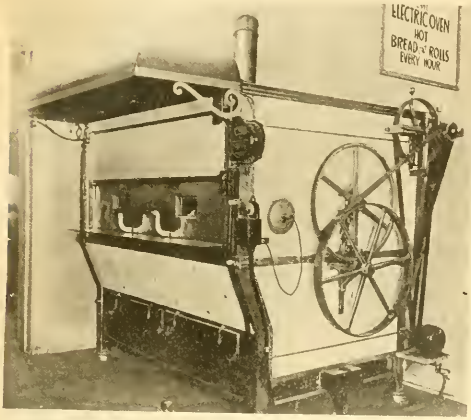

FIG. 1—REVOLVING OVEN, WITH GAS HEATERS REPLACED BY ELECTRIC HEATERS
Installed at McCann's Bakery, Pittsburgh.

of the revolving type of oven, exhaustive experiments were conducted by substituting electricity for gas in an oven of this general construction, with results that were highly satisfactory in every detail. The oven shown in Fig. 1 is a gas oven equipped with standard electric heaters and automatic temperature control, which has been operating successfully for over a year. The electrical equipment used has been operating successfully in many industrial plants throughout the country in applications of enameling and baking ovens for a number of years.

The matter of economy, however, introduced the principal objection to this combination and the next important step was a reduction of the radiation losses to the lowest possible figure. The result is the automatic electric bake oven of the type shown in Fig. 2, in which

FIG. 3—ELECTRIC OVEN IN THE DICKSON BAKERY, MANSFIELD, OHIO
The open door forms a convenient shelf.

the temperature is automatically maintained at any desired point without attention. Due to the inherently superior heating medium, a totally enclosed baking chamber replaces the non-insulated open oven which was required for the proper combustion of the gas used in many bake ovens.

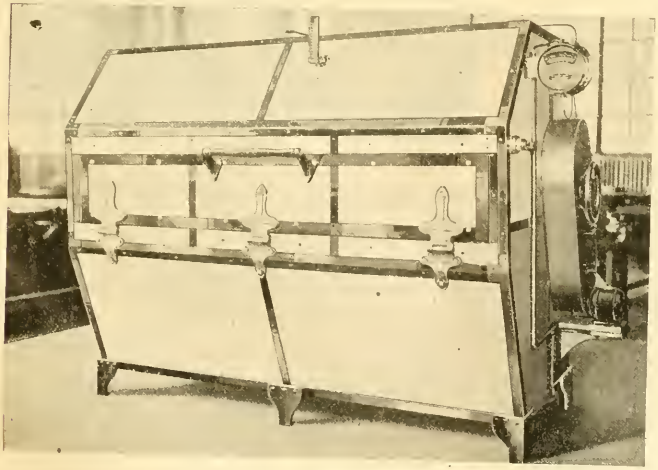

FIG. 2—AUTOMATIC ELECTRIC BAKE OVEN
Installed in the West Penn Hospital, Pittsburgh. Showing the location of the thermometer and thermostat.

These ovens are rated at 25 kw on any standard voltage. The objects to be obtained were uniformity of heat distribution; automatic control of temperature; low radiation losses; flexibility of design (easily adapted to a number of different requirements); reduced first cost of oven and operation; oven to be shipped assembled or nearly so; and oven to present a neat, clean, finished appearance. The first model constructed along these lines has been placed in a local bakery, Fig. 3 where it has been in daily operation for several months, turning out a very uniform product day after day.

The oven is finished in white vitreous enamel with nickel trimmings. The walls are packed with three inches of high grade heat insulating material and the oven contains eight trays attached to a reel which makes one complete revolution per minute. The door, when open, forms a shelf convenient for the loading and unloading of the baked products. The capacity of the oven depends upon the products baked and the size of pans used. It will bake 96 standard 24 oz. loaves and 120 one pound loaves at one time or approximately

150 large loaves and 200 small loaves per hour.

The automatic control feature centered in the electric thermostat insures the proper baking temperature without any attention whatsoever. After the oven is connected to the circuit by the mere pushing of a

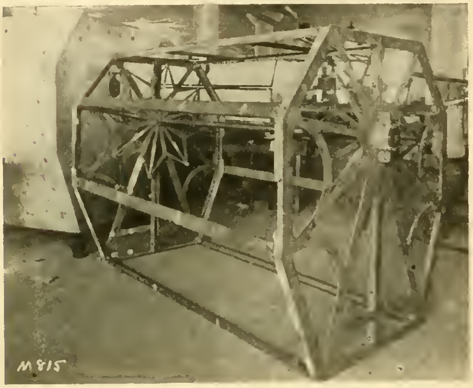

FIG. 4—OVEN FRAMEWORK

button, the baker is assured that the proper baking heat is being maintained with absolute certainty, bake after bake and day after day without the least attention on his part. It is maintained automatically, and even though the oven is idle for a short period the thermostat turns the heat on and off and keeps the baking temperature inside the oven within very close limits. In fact the oven, with its control accessories, is almost human in its operation and allows the baker to prepare his bread under the most ideal conditions and secure maximum output with almost clock-like regularity.

Even though the heaters are rated at 25 kw maximum, the automatic control equipment turns the heat-

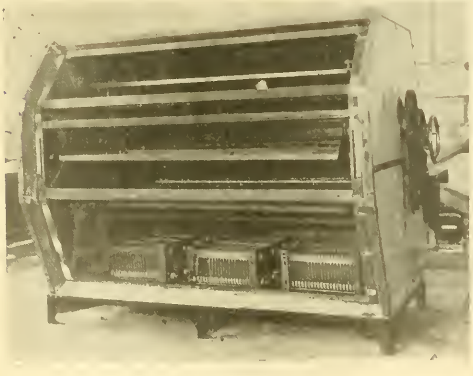

FIG. 5—HEATER INSTALLATION

ers on and off in its functioning to maintain the proper baking temperature and as a result the actual power consumption is considerably less than the maximum and averages from 18 to 20 kw-hrs. depending upon the products baked. The insulated baking chamber, with its almost negligible radiation losses, can be brought to a baking temperature of 450 degrees F. in 45 minutes.

With an electric oven which is controlled automatically, the bake shop assumes the aspect of a well-regulated factory, as the old rule of thumb methods are replaced by systematic routine. Since all operations of these ovens can be reduced to a positive time basis, the whole scheme of baking becomes a cyclic operation with the positive assurance that every 35 minutes one bake can be removed and the next placed in the oven with no intermediate attention whatsoever. This feature allows the baker to time all other operations of his shop so that a steady stream of dough from the forming rolls through the "proofing" chamber will be ready to refill the oven at the end of each baking cycle. This saves time, labor, confusion and makes for economy and maximum production in the smallest space.

As gas ovens and non-automatic electric ovens require so much attention to gas valves and control switches, this systematizing of the bakery is almost out

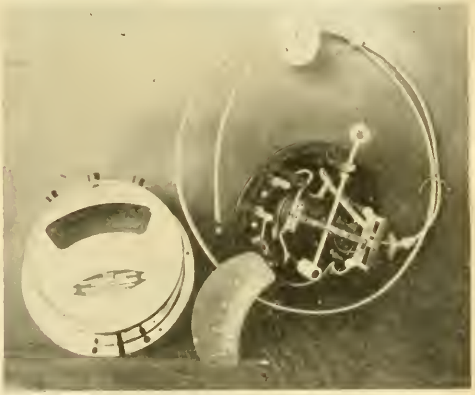

FIG. 6—THE CONTROL THERMOSTAT

of the question with them. Either the oven has to be brought to the right temperature while the bread waits and over-proofs, or the bread is put into the oven when it is properly proofed, regardless of the oven temperature. No labor or time is saved with these ovens and you can not judge by one bake what the quality of the next will be.

Details of construction of the new oven are shown in Figs. 4 and 5. As will be seen this oven is built as a building is constructed;—cast iron angle-section end frames tied together with structural steel angles and channels form the interior frame work upon which the unit panels of the oven walls are supported. These panels are made of galvanized sheet steel on the outside, a rust resisting black sheet steel on the inside and filled between with three inches of "felted" mineral wool which is one of the best heat insulators known, besides possessing other necessary qualities such as being "non-settling", light, non-hydrating and having a distinct springiness, so that it can be packed into a space

and will exert a force outward, insuring that the space will remain filled. The number of bolts going into the oven is small, thus reducing the "through metal" losses to a minimum. The supporting hooks for the unit tray

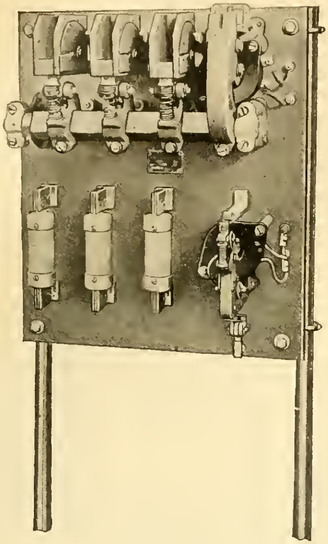

FIG. 7—THE CONTROL PANEL

or shelf are composed of bronze with grooves inlaid with graphite, thus needing no further lubrication. The hooks afford a ready means of removing trays from oven through the door or replacing them. The tray bottom is perforated to allow free circulation of the

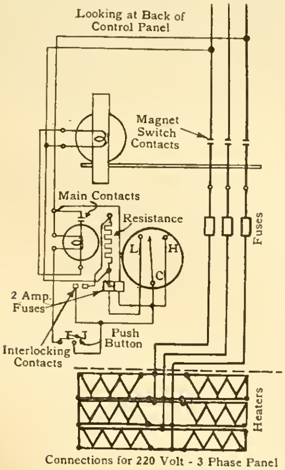

FIG. 8—SCHEMATIC DIAGRAM OF AUTOMATIC TEMPERATURE CONTROL

heated air round the work, and a back stop is provided in order that work will not be pushed over the back edge of the tray.

A detailed view of the control thermostat is shown in Fig. 6 and the control panel in Figs. 7 and 8. The thermostat is mounted on the end of the oven with the bulb inserted in the middle of the oven top but the control panel can be located where most convenient, in the basement, adjacent room, or as is frequently done, mounted high up on the wall.

An adjustable baffle plate is mounted directly above the heaters; as is well known, the highest end of the

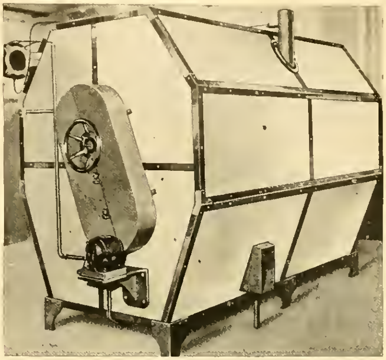

FIG. 9—MOTOR AND GEAR DRIVE

oven will be the hottest unless compensated for. By raising or lowering this baffle plate, both ends of the oven can be made to bake alike, even though the oven itself is not level. The revolving "ferris wheel" is rotated by a 1/6 hp motor through suitable reduction gears Fig. 9, to give slightly less than one r.p.m. on the reel. The motor pinion is bakelite-micarta which gives noiseless operation of the gears. The reel shaft rides in bronze-graphite bearings, so it does not have to be

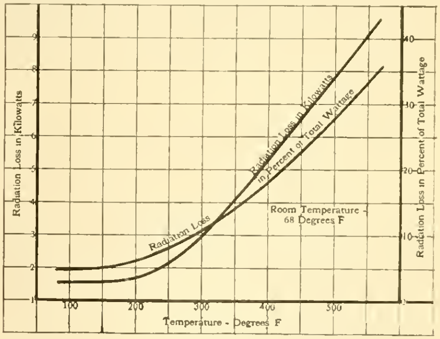

FIG. 10—CONSTANT RADIATION LOSS AT DIFFERENT BAKING TEMPERATURES

lubricated otherwise. Lubricating oil would not stand the temperatures these bearings reach, approximately 500 degrees F. A vent pipe is provided, because baking bread gives off considerable carbon dioxide and other disagreeable gases which affect the eyes and nostrils, and so should be carried outside the room.

Curves in Figs. 10 and 11 show the characteristics of this oven. The time of heating the oven up to bak-

ing temperature is 45 minutes, as compared with 2.5 hours on the converted gas oven referred to in the first part of this article, and the radiation loss at 450 degrees F. is approximately one-third of the loss shown at the same temperature in the converted gas oven. Fig. 12 shows a recording thermometer chart taken on the Westinghouse automatic oven.

TABLE I—POWER REQUIRED FOR BREAD BAKING*

No. of Bakes	No of Loaves	Total Kw-Hr Required for Run		Watts Required per Load	
		Continuous Baking	Intermittent Baking	Continuous Baking	Intermittent Baking
1	96	33.2	52	346	540
2	192	47.2	64.7	246	350
3	288	61.2	100.5	212	337
4	384	75.2	128	196	334
5	480	89.2	137	185	286
6	576	103.2		179	
7	672	117.2		175	
8	768	131.2		171	
9	864	145.2		168	
10	960	157.2		166	

From Table I it will be seen that the watthours and hence the cost per loaf, decreases as the number of bakes per day is increased. These figures are based upon continuous baking and will be increased as the idle time between bakes is increased, so that it is greatly to the advantage of the baker to operate these ovens continuously.

The automatic temperature control produces many distinct advantages, chief among which are:—The baking temperature is uniform, regardless of whether the oven is completely loaded or not, insuring a uniform product and the ability to duplicate results day after day. No attention need be paid the oven other than to put in the bread and take it out at the proper time. By permitting the operator to give his entire attention to other details during the baking period, considerable labor saving is effected.

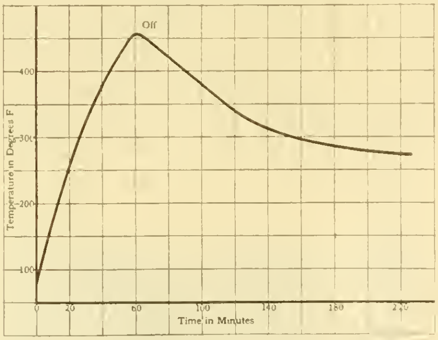

FIG. 11—TEMPERATURE WITH CONSTANT INPUT
Room temperature, 68 degrees F.

*Oven loaded with 96 one and one-half pound loaves per bake; temperature 500 degrees F; time of bake 33 minutes. If proper pans are used this oven will hold 112 one and one-half pound loaves per bake.

The complete thermal insulation not only affords a considerable saving in electricity but permits a cooler workroom. This feature permits the installation of the oven directly in the sales or display room of the bakery without inconvience to customers. The advertising feature of baking bread and cakes scientifically and under complete sanitary conditions by electricity, places the baker immediately in an up-to-date and progressive class. Due to the elimination of combustible gases the fire hazard is entirely eliminated.

There is a wide field of application of the automatic bake oven aside from its use in bakeries. Hotels, restaurants, hospitals and public institutions, private clubs and large industrial plants all have a demand for fresh bread, rolls, specially baked cakes or fancy pastries, which can be turned out, with such equipment, just when needed, at minimum cost, and of the highest quality. For such applications, neat and attractive appearance is an asset surpassed only by the clean and sanitary arrangement, the uniformity of product and the economy of operation.

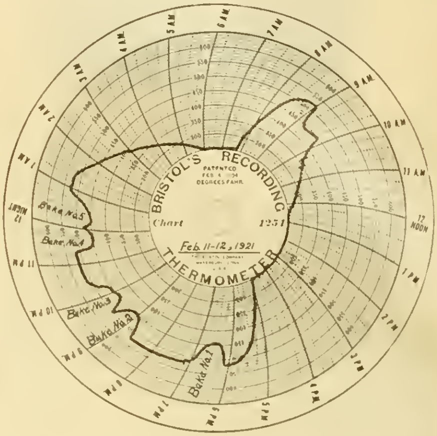

FIG. 12—TEMPERATURE MAINTAINED DURING SUCCESSIVE BAKES

From the standpoint of central stations, these ovens will add a desirable load. The phases are balanced, the load is at 100 percent power-factor, and in most bake shops will come at "off peak" hours, as the day's bake usually starts soon after midnight, when all central station loads are lowest, especially in the smaller towns cities.

Electrically Operated Grain Car Unloaders

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THE Northern Central grain elevator of the Pennsylvania Railroad Company at Baltimore, Maryland has a grain storage capacity of approximately five million bushels, only half that of the largest Canadian storage elevators, but in grain handling capacity it is twice as large as any other elevator. Located on the harbor front, its piers can accommodate five ocean going vessels at one time. It is equipped with the latest and most modern type of machinery designed for the most efficient handling of bulk grain.

Foremost among the many labor and time saving devices are the grain car dumpers in the unloading room. Four of these machines, side by side, with an operating crew of eighteen men, can unload four hundred cars daily, each car containing from 1200 to 2000 bushels of grain. The average is twenty-five to thirty cars per dumper in each eight hour shift, with only three men actually assisting in the dumping operation. Prior to the installation of these machines, four men were required to unload eight cars in eight hours. The average time for unloading one car is ten minutes. During the operation of unloading 314 cars, it was observed that one-third of them were unloaded completely in eight minutes each.

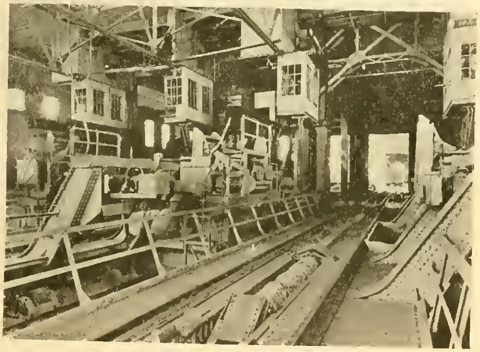

FIG. 1—UNLOADING ROOM

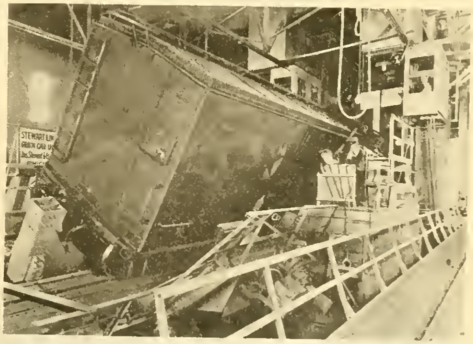

FIG. 2—CAR TILTED 30 DEGREES TO ONE SIDE

These facts become more impressive when it is remembered that grain is shipped in standard size box cars with side opening doors and separate wooden grain doors usually nailed to the framework of the car. After the doors are opened the car is emptied by tilting it in several directions to permit all of the grain to flow out of the car door. Small cars are tilted once each way only and large cars are tilted twice.

The car dumpers were designed and built by the Link Belt Company, were installed under the direction of Jas. Stewart & Co., Inc., grain elevator contractors, and were made unusually heavy because they were required to sustain the weight of locomotives passing over them. They consist of a bridge approximately 60 feet long, supported on a large central shaft in trunion bearings and arranged to be tilted 45° in either direction endwise and 30° sidewise in one direction. Automatic means for clamping the cars in place on the bridge are provided at the ends and sides of the cars and automatic means of opening and lifting grain doors are included. A motor-operated car puller is used to pull up a string of loaded cars and to spot the cars in the center of the bridge.

The cycle of operation begins with the bridge horizontal, with end posts under each end to prevent endwise tilting, with end clamps depressed below the level of the track to permit cars to be run onto the bridge, with side clamps and door openers backed away from the bridge in extreme positions. The operator manipulates the car puller to pull a car to the approximate center of the bridge. The end clamps are then run up against the bumpers. The end clamp motors drive the clamps through screws and travelling nuts and are stopped by current limit relays when the clamps have exerted sufficient pressure against the couplings to stall the motors. After the end clamp motors have been stopped in this manner, it is possible to operate the side clamp motors, one at either end of the car, to push out the side clamps which are intended to support the car as it tilts over sidewise. Current limit relays are also used to stop these motors, and after the motors have been stopped in this manner it is possible to run the door opener forward to push in the grain door. The car door has been opened previously to prevent damage to the car.

The original layout included a motor and control for lifting the grain door above the floor of the car to permit escape of the grain before the car was tilted.

This motor was not used, however, and the door is lifted manually by means of levers.

Lifting the grain door permits grain to begin to flow out of the car and in order to accelerate this flow of grain, the car is tilted 30 degrees sidewise at which time the electrical circuits are completed which enable the operator to remove the end posts, and to tip the car 45 degrees endwise. The car is tipped to the other extreme position and then restored to a horizontal position and unclamped by the reverse of the cycle just described.

FIG. 3—CAR TILTED ENDWISE
Showing the inclined position of the platform on which the workmen stand.

When the car has been entirely emptied, the end post under the elevated end of the bridge is inserted and the bridge is started down toward that end. Insertion of the end post brings into operation an auxiliary limit switch which causes the bridge to slow down an stop in the mid or horizontal position at which time the other end post is put under. The car is then restored to a horizontal position and unclamped by first removing the door pusher and side clamps, and is pushed off the bridge by the next loaded car.

FIG. 4—CAR TILTED IN OPPOSITE DIRECTION
Showing the bridge mechanism and part of the concrete counterweight.

All the operations are completely interlocked so as to make it absolutely necessary to adhere to a predetermined cycle of operation and any departure from this predetermined cycle immediatey makes the control inoperative and makes it necessary for the operator to hold down some push buttons while correcting faulty operation and restoring the action of the control to its previous condition.

The power supply is three-phase, 25 cycles, 550 volts alternating current, and the motors used are of both the squirrel-cage and the wound-rotor induction type. The main controllers are in the form of switchboards on which are mounted the necessary magnetically-operated contactors, relays, etc. The operator's switches are small drum type controllers, one for each operation of the dumper. All of this equipment must be enclosed in order to avoid dust explosions. All of the limit switches mounted on the dumpers are enclosed in dust proof boxes. The wound-rotor motors, with exposed current carrying parts, are covered and the control panels are mounted in dust proof houses at the top of the unloading room where they are farthest removed from the source of dust. The operators' compartments, below the control house, are encased in glass.

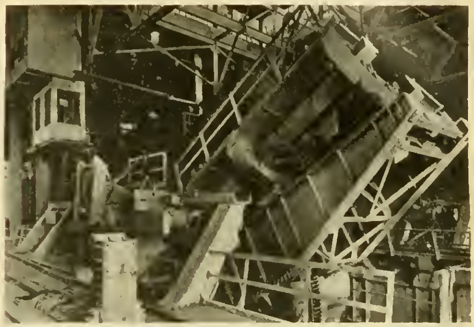

FIG. 5—VIEW FROM OTHER SIDE OF DUMPER
This illustration gives a good idea of the arrangement of the door pusher and side bolsters on the adjacent track.

A general view of the unloading room is given in Fig 1. The dumper in the foreground is in position to receive a loaded car. End clamps are down in the pits beneath the track level; side bolsters and door pusher are backed out to their limits to avoid striking the approaching car. At the right near the center is the top of the hopper into which the grain is poured. The operators' compartments are built out from the columns at the side of and above the dumpers to give the best possible view of the unloading operation. The controller houses are directly above the operating rooms. This view shows also the construction of the side bolsters and door pusher. The top part of the bridge, on which are mounted the end clamps and side bolsters, is a cradle which is rotated on the rollers shown in the left foreground to tilt the car sidewise.

The door pusher does not tilt with the cradle. It is pushed out securely against the grain doors and removes this door on account of the relative motion between the door pusher and the car as it tilts sidewise.

A car is shown in Fig. 2 clamped in the cradle and tilted to the extreme side position. The operating crew consists of three men. The end clamps rise out of the pits as they are pulled forward and when they strike the car couplings they continue until the pressure

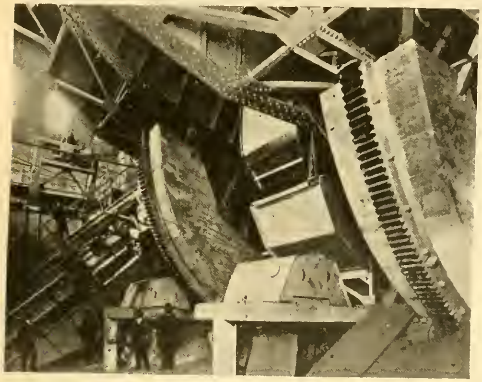

FIG. 6—BOTTOM OF CAR DUMPER

The grain hopper and cover over the end tilted motor, as well as the counterweights and gear drive are plainly shown.

exerted stalls the end clamp motor. A current limit relay on the control panel disconnects the motor after it has been stalled. Prior to this, due to interlocking of the control circuits, no other part of the dumper can be operated and after its occurrence only the side bolsters can be moved. There are two of these, one at each end of the car. Both must be moved out against the car and both operating motors must be stalled before any more of the control is energized.

Both the end clamps and the side bolsters may be run back and forth as often as desired before they are stalled but after either one has been stalled and the succeeding operation has been started, then an attempt to operate either of them will immediately de-energize all the control and effectually prevent unclamping the car when it may be in an unstable position. The same idea is carried out in the complete cycle of operation and is effective in both directions; i. e., whether the car is being clamped and unloaded or being returned to normal position and unclamped. To restore normal conditions, the operator must hold down push buttons at some little trouble until he has corrected his mistake.

When the side bolsters have been stalled, the control for the door pusher motor and the side tilting motor are energized. The door pusher advances, strikes the grain door, pushes the boards into the car, and stops automatically. The car tilts sidewise until stopped by the opening of a geared limit switch controlled by the side tilting motor. The same limit switch establishes a circuit which releases magnet-operated latches on the end posts and thereby makes it mechanically possible for the operator to remove these end posts. Levers for this purpose are mounted in the operating room.

Switches operated by the removal of the end posts complete the circuit for the end tilting control and permit the bridge and car to be tilted endwise, as shown in Figs. 3 and 4. A geared limit switch automatically causes the tilting motor to slow down and stop at the extreme positions. A two-speed induction motor is used for this purpose. The slow-speed connection is useful in giving a positive slow down before the bridge comes to rest and the brake is set. The bridge is partially counterweighted, as shown in Figs. 4 and 6. In practice it is always tilted first in the direction which lifts the counterweight. Then the weight is able to assist in moving the unbalanced load of the partly empty car in the other direction.

When the car has been emptied and it is desired to stop the bridge in the horizontal position, the operator replaces the end post under the elevated end of the bridge. This action cuts in an auxiliary limit switch which automatically slows down and stops the motor when the bridge is approximately horizontal. Exact spotting level with adjacent tracks is done from an "inching" push button which is effective only when the bridge is nearly in place on the end posts. When the operator replaces the second end post, the side tilt control, which is de-energized as long as either end post is removed, is again energized and the car may be brought to a level position. When it reaches this position, other contacts on the side tilt limit switch re-establish the circuit for the side bolsters and door pusher. These, in turn, when they have reached their

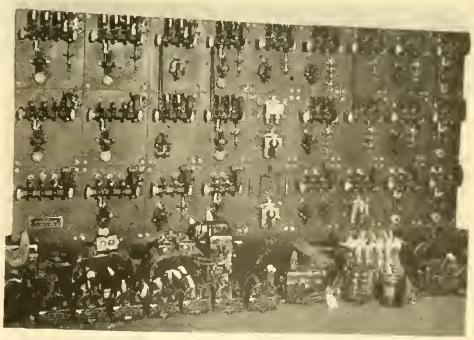

FIG. 7—CONTROL PANEL WITH THE AUXILIARY CONTROL APPARATUS

extreme position away from the car, re-establish the circuit for the end clamp control and the car can be completely released. From this point, it is pushed off the bridge by the next oncoming car.

It will be seen from the above description that exacting interlocking requirements have been met. No operation can be started until the preceding one has

been completed. The value of the precautions taken is emphasized by the entire freedom from accidents while handling cars. So perfectly has the interlocking been worked out that the complete cycle of unloading, when once started, may be automatic. All that is necessary is for the operator to put his control handles into the running position. If desired, he could move all handles at the same time. The interlocking would assure correct functioning of all parts of the equipment through an unloading cycle.

Some Features of the Cottrell Plant at the Hayden Smelter

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Chief Electrician,
Hayden Smelter

THE Hayden plant of the American Smelting & Refining Co., at Hayden, Arizona, is designed for the production of copper bullion from sulphide ores. In accordance with standard practice the crude ore and concentrates are first run through roasters where they are heated to a high temperature and the moisture and a portion of the sulphur content are driven off. The smoke or gases coming from the roasters carry a considerable amount of solid matter, a portion of which is copper. The gases first pass through a dust chamber where the heavier particles settle by gravity and then to the Cottrell precipitator. Here the remainder of the solid matter is recovered by electrostatic precipitation.

Each chamber has four groups or sections of five pairs of screens each, space being left in each chamber for two more sections in case the installation of additional screens should prove to be desirable later on. Each chamber is provided with a damper at each end and a short connecting flue joins the dust chamber extension to the main flue. The top of the chambers is covered over by a steel deck.

The screens are made of No. 8 iron wire with a 2.5 inch square mesh and are 8.5 feet wide, 12.5 feet long and have a one inch channel iron frame. The spacing between screens is six inches and adjacent pairs are spaced twelve inches. Baffles placed at the top and bottom prevent the gases from taking any path other than through the screens, and vertical spacing strips between the screens avoid the possibility of their warping out of line.

FIG. 1—EXTERIOR VIEW OF PRECIPITATOR

FIG. 2—PRECIPITATOR AND CONNECTING FLUE

FIG. 3—INTERIOR OF ONE CHAMBER OF PRECIPITATOR

The Hayden plant is a radical departure from the usual type of Cottrell precipitator in that the positive electrodes consist of a series of vertical pairs of grounded wire screens and the negative electrodes are uniformly spaced wires placed between each pair of screens. The gas travels at right angles to the plane of the screens*.

In the construction for the precipitator the old dust chamber was extended sixty-two feet and divided longitudionally into four divisions or chambers by three brick partitions. Wooden strips were placed vertically on the walls which were then gunited to a depth of about two inches. The strips were later removed and the screens slipped down into the resulting slots.

The negative electrodes are made of No. 14 iron wire and, for each section, are held at the top and bottom by a framework fastened to four vertical I-beams which pass through the steel deck and are supported by a channel-iron frame resting on four porcelain insulators. At the point where the I-beams pass through the steel deck they are insulated by means of micarta cylinders, twelve inches in diameter and fourteen inches long, each being provided with a cover which fits closely around the I-beam and keeps out cold air. Each wire is kept in tension by means of a coil spring at the bottom. Approximately eighteen wires are uniformly spaced between each pair of screens,

*This type of precipitator was developed by Mr. R. B. Rathbun, who designed the Hayden Cottrell plant in detail and supervised its installation

making a total of three hundred and sixty wires to the chamber.

The dust is shaken from the screens by a system of shaker bars which are hung from the top below the steel deck and work back and forth against a striking plate near the center of each screen. For each chamber the bars are operated by a single lever. The negative electrodes for each section are shaken by a vertical rod so arranged that it can be raised and dropped on the framework supporting the wires. When not being operated it is fastened up out of the way. The dust collected falls down into hoppers and is removed by larry cars.

Each chamber is partitioned off from the others and has a high-tension switch, operated by the door, which opens the circuit for that chamber. Each chamber has also an automatic grounding device, operated by the opening of the door, which effectually grounds the electrodes. There is also a safety device which keeps the door from being accidentally closed.

The electrical equipment is housed in a separate building near the precipitator. There are four 15 kv-a motor-generator sets, four 15 kv-a transformers provided with taps which give a voltage from 22 500 to 45 000, a motor-driven exciter, an electrostatic voltmeter and a switchboard containing the necessary circuit breakers and instruments. The exciter capacity is such that additional motor-generator sets can be installed later on. The rectifiers are of the well known Lemp switch type. A 28 inch micarta disk carries the revolving contacts and is mounted on a shaft extension of the motor-generator; the stationary contacts are mounted on a micarta disk which is so arranged that it can be rotated through ninety degrees. The positive leads from each rectifier run to a milliammeter on the switchboard and thence to the ground. The negative leads run to a system of overhead buss wires. These, together with hook connectors, permit the connection of any section in the treater to any machine.

The precipitator was designed to handle the gases from twelve roasters, the total volume being approximately 190 000 cubic feet per minute. The gas velocity in the chambers is about eight feet per second, and the temperature at the entrance ranges from 100 to 350 degrees F., the average temperature being about 250 degrees. Ordinarily the drop in temperature in the treater is about 25 degrees. The amount of sulphuric acid in the dust ranges from 0.5 to 40 percent. The power consumed per ton of dust recovered runs about 60 kw-hr. The average working voltage is 24 000 volts and the current from the rectifiers runs about 150 milliamperes. Under average conditions three machines are run at one time, the fourth being reserved as a spare. Tests have shown the recovery to be but slightly less than 100 percent.

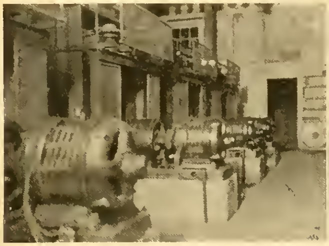

FIG. 4—INTERIOR OF RECTIFIER BUILDING

FIG. 5—RECTIFIER BUILDING

FIG. 6—HIGH TENSION ELECTROSTATIC VOLTMETER

This plant has been in continuous operation since its completion in January, 1920 and the results have been very gratifying. It was installed and is being operated solely to recover the copper content of the roaster gases which otherwise would be lost. The value of the copper recovered is such that the complete Cottrell installation will be paid for in a relatively short time and thereafter will yield a handsome dividend on the investment.

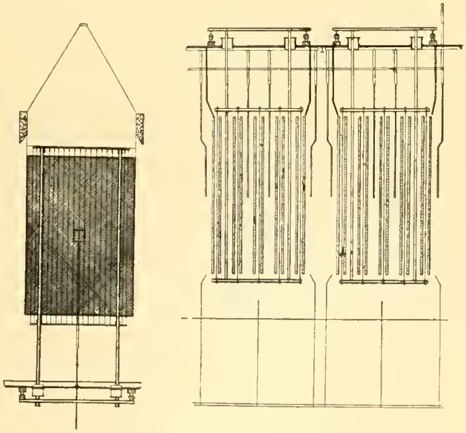

FIG. 7—ASSEMBLY OF POSITIVE AND NEGATIVE ELECTRODES

Transmission Line Circuit Constants and Resonance

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General Engineers,
Westinghouse Electric & Mfg. Company

THE PROBLEM of obtaining the characteristics of a transmission system, including transformers, frequently arises. The voltage drop through the transformer is usually so large that it cannot be neglected. In general, the addition of a transformer to a transmission system changes the system characteristics considerably.

The usual transmission problem involves a step-up and a step-down transformer and a transmission line. This problem may be considered as one involving three networks in series, as indicated in Fig. 1

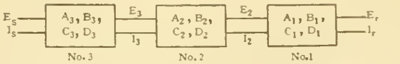

FIG. 1

The networks *1, 2* and *3* have constants A, B, C and D suitably distinguished by subscripts. These constants* are defined by the following equations:—

$$E_2 = A_1 E_r + B_1 I_r$$
$$I_2 = C_1 E_r + D_1 I_r$$
$$E_3 = A_2 E_2 + B_2 I_2$$
$$I_3 = C_2 E_2 + D_2 I_2$$
$$E_s = A_3 E_3 + B_3 I_3$$
$$I_s = C_3 E_3 + D_3 I_3$$

Networks *1* and *2* may be replaced by a single network, with constants determined by eliminating E_2 and I_2 from the first four equations given above. This process may be repeated to replace the three networks by a single network. The resultant constants A_0, B_0, C_0 and D_0 for three networks are as follows:—

$$A_0 = A_3 (A_1 A_2 + C_1 B_2) + B_3 (A_1 C_2 + C_1 D_2) \ldots\ldots (1)$$
$$B_0 = A_3 (B_1 A_2 + D_1 B_2) + B_3 (B_1 C_2 + D_1 D_2) \ldots\ldots (2)$$
$$C_0 = C_3 (A_1 A_2 + B_2 C_1) + D_3 (A_1 C_2 + C_1 D_2) \ldots\ldots (3)$$
$$D_0 = C_3 (B_1 A_2 + D_1 B_2) + D_3 (B_1 C_2 + D_1 D_2) \ldots\ldots (4)$$

The corresponding constants for two networks *1* and *2*, are as follows:—

$$A_{00} = A_1 A_2 + C_1 B_2$$
$$B_{00} = B_1 A_2 + D_1 B_2$$
$$C_{00} = A_1 C_2 + C_1 D_2$$
$$D_{00} = B_1 C_2 + D_1 D_2$$

Different networks have different values for the A, B, C, and D constants. The characteristics of these constants for three simple networks are listed in Table I.

TABLE I—CIRCUIT CONSTANTS FOR TYPICAL NETWORKS.

Shunt Admittance	Series Impedance	Transmission Line
$A = 1$	1	$\cosh \sqrt{ZY}$
$B = 0$	Z	$\sqrt{\frac{Z}{Y}} \sinh \sqrt{ZY}$
$C = Y$	0	$\sqrt{\frac{Y}{Z}} \sinh \sqrt{ZY}$
$D = 1$	1	$\cosh \sqrt{ZY}$

It is now a simple matter to determine the general circuit constants for the case of a transmission line with step-up and step-down transformers, as indicated in Fig. 2, where T_r = the receiver transformer impedance, and T_s = the sending transformer impedance.

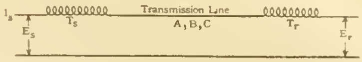

FIG. 2

The network in Fig. 2 may be considered as being composed of three simple networks in series, a series impedance, a transmission line and another series impedance with constants as given in Table II.

From these constants, the general circuit constants can be obtained by substitution in equations (1), (2), (3) and (4) and are as follows:—

TABLE II.—CIRCUIT CONSTANT FOR FIG. 2.

$A_1 = 1$	$A_2 = A$	$A_3 = 1$
$B_1 = T_r$	$B_2 = B$	$B_3 = T_s$
$C_1 = 0$	$C_2 = C$	$C_3 = 0$
$D_1 = 1$	$D_2 = A$	$D_3 = 1$

$$A_0 = A + CT_s \ldots\ldots (5)$$
$$B_0 = B + A (T_r + T_s) + T_r T_s C \ldots\ldots (6)$$
$$C_0 = C \ldots\ldots (7)$$
$$D_0 = A + CT_r \ldots\ldots (8)$$

Another interesting case is that of a transmission line with a shunt loading in the middle as shown in Fig. 3. In general, a capacity loading would be employed, so as to increase the amount of power which may be transmitted over the transmission lines. In this case, the constants for each network, a transmission line, a shunt admittance and another transmission line, are as given in Table III.

*For a transmission line or other symmetrical system the D constant is equal to A. Thus for a transmission line by itself, the relations between generator and receiver voltages and currents may be expressed in terms of the three constants, usually designated as A, B and C, as given by Mr. Nesbit in his series on "Electrical Characteristics of Transmission Circuits" in the JOURNAL for March and April 1920. The D constant is employed in the accompanying equations, so as to provide for the general case. The use of the D constant is necessary when the transmission system is unsymmetrical about its center; for example, a transmission line with dissimilar transformers at each end.

From these constants, the general circuit constants can be obtained by substitution in equations (1), (2), (3), (4), and are as follows:—

$$A_0 = A^2 + BC + BA\,Y_m$$
$$B_0 = 2AB + B^2\,Y_m$$
$$C_0 = 2\,AC + A^2\,Y_m$$
$$D_0 = A^2 + BC + BA\,Y_m$$

If Y_m in the above formula is set equal to zero. the constants for a transmission line of double length are obtained in terms of constants for single length.

TABLE III—CIRCUIT CONSTANTS FOR FIG. 3.

$A_1 = A$	$A_2 = 1$	$A_3 = A$
$B_1 = B$	$B_2 = 0$	$B_3 = B$
$C_1 = C$	$C_2 = Y_m$	$C_3 = C$
$D_1 = A$	$D_2 = 1$	$D_3 = A$

When the conditions at one end of the transmission system are known, the conditions at the other end can be expressed in terms of the general circuit constants, with equations as stated below:—

$$E_s = A_0\,E_r + B_0\,I_r \ldots\ldots (9) \qquad E_r = A_0\,E_s - B_0\,I_r \quad (11)$$
$$I_s = C_0\,E_r + D_0\,I_r \ldots\ldots (10) \qquad I_r = -C_0\,E_s + D_0\,I_r \ldots (12)$$

In the first case, shown in Fig. 2, for which the general circuit constants were developed above, it will be noted that the exciting kv-a, has been neglected. However, this can be readily taken into account in a similar way by considering the transformer as a particular network and working out the general circuit constants accordingly. Hence, it appears convenient to employ general circuit constants A_0, B_0, C_0 and D_0 for the entire transmission system, instead of the A, B, C constants for the transmission line by itself, and making separate calculations for each transformer.

RESONANCE

The practical cases from which resonance usually arise involve a transmission line and the transformaers. The resonant condition for the transmission line by itself is considerably changed by the addition of transformers. In determining the conditions for resonance of a transmission system involving transformers, the desirability of employing general circuit constants will be brought out.

The two resonant conditions which will be considered are: —

Case I—With receiver open.
Case II—With receiver closed.

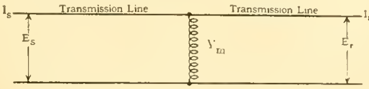

FIG. 3

Case I—The transmission system may be represented by the diagram, Fig. 2. In this case, the receiver is open and $I_r = 0$. The power at the generator is, from equations 9 and 10,—

$$E_s\,\overline{I_s} = A_0\,\overline{C_0}\,E_r^2 \text{*}$$

*Where $\overline{I_s}$ and $\overline{C_0}$ are conjugates of I_s and C_0. The conjugates of any vector quantity are obtained by changing the sign of the j term.

The condition for resonance is that the reactive power be equal to zero, that is

$$(A_0\,\overline{C_0} - \overline{A_0}\,C_0) = 0$$

If the resistance and leakage resistance be neglected. the resonant condition (as shown in the appendix) may be stated as follows:—

$$\tan 2\pi f l \sqrt{LC} = \frac{\sqrt{L}}{2\pi f L_s \sqrt{C}}$$

Where L=transmission line inductance per mile
C=transmission line capacity per mile
L_s=step-up transformer inductance
f=resonant frequency
l=length of transmission line

In case L_s is zero, the condition for open circuit resonance on a transmission system without transformers is obtained and is as follows:—

$$\tan 2\pi f l \sqrt{LC} = \infty$$
$$\text{Hence, } 2\pi f l \sqrt{LC} = \pi \div 2$$
$$f = \frac{1}{4 l \sqrt{LC}}$$

It is to be noted that the shortest length of line for resonance, which is the quarter wave length, corresponds to an angle in the first quadrant, as is denoted by the positive sign. For any positive value of L_s it is obvious that the tangent of the angle must be less than infinity, and hence the angle is less than one-half π.

Case II—The transmission system may be represented by the diagram shown in Fig. 4. For this condition, $E_r = 0$ and the generator power is,—

$$E_s\,\overline{I_s} = B_0\,\overline{D_0}\,(I_r\,\overline{I_r})$$

The condition for resonance is that the reactive power be equal to zero which is,—

$$(B_0\,\overline{D_0} - \overline{B_0}\,D_0) = 0$$

If the resistance and leakage resistance be neglected, the resonant condition, as shown in the appendix, may be stated as follows:—

$$\tan 2\pi f l \sqrt{LC} = \frac{-2\pi f (L_r + L_s)}{\sqrt{\frac{L}{C}} - (2\pi f)^2 L_s L_r \sqrt{\frac{C}{L}}}$$

Where the notation is the same as given in Case I and with L_r equal to the receiver transformer inductance. In case the transmission line is short-circuited at either end, so that only one transformer is included the resonance condition is obtained by simplifying the

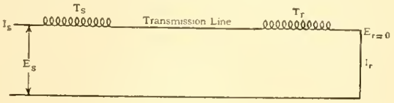

FIG. 4

above formulas and setting either L_r or L_s equal to zero. The condition for closed circuit resonance of a transmission line by itself is obtained by setting both L_r and L_s equal to zero, which gives,—

$$\tan 2\pi f l \sqrt{LC} = -0$$
$$\text{hence } 2\pi f l \sqrt{LC} = 180^\circ = \pi$$
$$f = \frac{1}{2 l \sqrt{LC}}$$

It is to be noted that the shortest length of line for resonance, which is the half wave length, corresponds to an angle in the second quadrant when the tangent is negative, and in the first when it is positive. Values in the first quadrant are possible only when

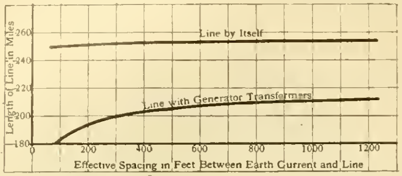

FIG. 5—RESONANCE AT 180 CYCLES OF A TRANSMISSION SYSTEM
Without ground wire and with receiver open, as shown in Fig. 2.

L_r and L_s are large enough to make the denominator of the fraction in the general equation negative.

RESONANCE CALCULATION FOR A PARTICULAR SYSTEM

In order to show what effect transformer impedance has on resonance, a 220 kv, three-phase, 60 cycle, 250 mile transmission line will be considered, with 500 000 circ. mil copper conductors, with 21 ft. equivalent spacing at an average height of 50 ft. above ground, with a 50 000 kv-a bank of 10 percent reactance transformers at each end.

The natural frequency for each condition as shown in Table IV is obtained by calculating the constants and substituting in the equations given above.

The above conditions for resonance have been considered for a polyphase system. With a grounded neutral system there is the condition for resonance as a single-phase system, with the transmission wires as one side of the circuit and the earth as the return. In case the transmission line is equipped with a ground wire, the return current may flow through the ground wire and through the earth, depending on the relative admittance of these paths. The formulas given above apply to these conditions, but the constants must be derived with reference to the actual path which the current takes. The constants of the circuit with ground wire returns may be calculated in the usual

TABLE IV—NATURAL FREQUENCY OF THREE-PHASE, 60 CYCLE TRANSMISSION LINE

Condition	Resonant Frequency	
	Case I	Case II
Line by itself	181	362
Line and generator transformer..	158	318
Line and both transformers		282

way. The circuit constants with earth return depend on the effective position of the earth current which is probably between the image of the conductors and 5000 feet below.

A grounded neutral system permits the flow of triple frequency currents. Triple frequency voltages are produced by the magnetizing currents of certain transformer construction and connections, such as star-star, two coil, or autotransformers. On this account, it is desirable to show the condition for resonance at 180 cycles. The inductance of the transformer is that which results when the line terminals are connected to one side of the circuit and the neutral to the other side. In the curves, shown in Figs. 5 and 6, for the resonance of a transmission system without ground wire, the inductance of the earth return has been considered as zero. In these curves, the length of the transmission line in miles is plotted against the position of the return current, expressed in feet below the transmission wires.

The important cases to be considered are the open circuit transmission line with generator transformer, and the closed circuit transmission line with both generator and receiver transformers. Perhaps it should be pointed out that a transmission line, employing transformers with grounded neutral at each end, provides a closed circuit for triple frequency, and the resonant condition is the normal operating condition, if the line is of sufficient length. In case of resonance, the current flowing is dependent on the voltage and resistance of the circuit. The maximum voltage on the transmission line may be calculated in the usual way

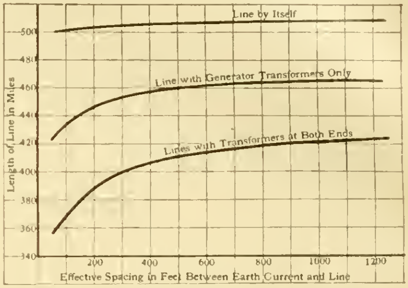

FIG. 6—RESONANCE AT 180 CYCLES OF TRANSMISSION LINE, FIG. 4, WITH RECEIVER CLOSED

from the voltage and current at one end. Dangerous triple frequency voltages may be avoided by employing a tertiary winding of suitable design, or by the use of an auxiliary transformer with delta connections to reduce the triple frequency voltage produced by the magnetizing currents.

APPENDIX

The resonance formulas may be simplified by neglecting resistance and leakage conductance, as indicated below:—

$$A = \cosh \sqrt{ZY} = \cosh 2\pi f l \sqrt{-LC} = \cos \pi f l \sqrt{LC} = \bar{A}$$

$$B = \sqrt{\frac{Z}{Y}} \sinh \sqrt{ZY} = \sqrt{\frac{L}{C}} \sinh 2\pi f l \sqrt{-LC} = +j \sqrt{\frac{L}{C}} \sin 2\pi f l \sqrt{LC} = -\bar{B}$$

$$C = \sqrt{\frac{Y}{Z}} \sinh \sqrt{ZY} = \sqrt{\frac{C}{L}} \sinh 2\pi f l \sqrt{-LC} = +j \sqrt{\frac{C}{L}} \sin 2\pi f l \sqrt{LC} = -\bar{C}$$

$$D = A = \bar{D}$$

$$T_r = +j\,2\pi f L_r$$

$$T_s = +j\,2\pi f L_s$$

Where L_r = receiver transformer inductance
and L_s = generator transformer inductance

Case I—The condition for resonance is that,—

$$(A_0 \overline{C}_0 - \overline{A}_0 C_0) = 0$$

For the network shown in Fig. 2, the constants given in equations 5 to 8, with $T_s = 0$ for open circuit receiver, may be substituted in the above equation, which gives when simplified the following expression:—

$$2\left[\cos 2\pi f l\sqrt{LC} - \sqrt{\frac{C}{L}}\,(\sin 2\pi f l\sqrt{LC})\,2\pi f L_s\right]\left[-j\sqrt{\frac{C}{L}}\sin 2\pi f l\sqrt{LC}\right] = 0$$

$$\tan 2\pi f l\sqrt{LC} = \frac{\sqrt{L}}{2\pi f L_s\sqrt{C}}$$

Case II—The condition for resonance is that—

$$(B_0 \overline{D}_0 - \overline{B}_0 D_0) = 0$$

For the network shown in Fig. 4, the constants given above with $T_s = +j2\pi f L_s$ for the closed circuit receiver, may be substituted in the above equation, which gives, when simplified, the following expression:—

$$2\left[+j\sqrt{\frac{L}{C}}\sin 2\pi f l\sqrt{LC} + j2\pi f(L_r + L_s)\cos 2\pi f l\sqrt{LC} + jL_r L_s (2\pi f)^2\sqrt{\frac{C}{L}}\sin 2\pi f l\sqrt{LC}\right] \times \left[\cos 2\pi f l\sqrt{LC} - \sqrt{\frac{C}{L}}\,(\sin 2\pi f l\sqrt{LC})\,2\pi f L_s\right] = 0$$

$$\tan 2\pi f l\sqrt{LC} = \frac{-2\pi f(L_r + L_s)}{\sqrt{\frac{L}{C}} - (2\pi f)^2 L_r L_s\sqrt{\frac{C}{L}}}$$

Starting Characteristics of Synchronous Motors

E. B. SHAND

UNTIL synchronous speed is reached no steady torque is exerted by a synchronous motor,* consequently the rotor is provided with a squirrel-cage or damper winding similar to that of an induction motor, which is relied upon to accelerate it nearly to synchronous speed. The complete starting operation includes all phenomena from the time of the first application of voltage to the time when steady operating conditions are reached. This comprises starting from rest and accelerating on reduced voltage, the applying of the excitation and the subsequent synchronizing of the motor, and the final transition to full running voltage. This order may not be strictly followed in certain cases—when, for instance, a motor will synchronize without excitation, or when it will either not start or not synchronize on reduced voltage—but probably in the greater number of cases this represents the sequence of operation.

On applying voltage to the armature winding with the machine at rest it is considered necessary either to close the field winding through a resistance, or to sectionalize it by means of a break-up switch, to protect its insulation from the abnormal voltages generated in it before the rotor has approached its synchronous speed. As the latter arrangement is not applicable to rotating field structures, the former scheme is generally used, although the details may depend somewhat upon the source of excitation employed. When the motor is excited from a direct-current bus the usual practice is to short-circuit the field winding with the normal rheostat resistance still in the circuit. As soon as the rotor approaches synchronous speed, the field switch is thrown over to the direct-current bus. When the motor is furnished with a direct-connected exciter, the same arrangement may be used, but it is more usual simply to leave the field connected directly across the exciter armature throughout the whole of the starting period. The exciter voltage rises roughly with the square of the speed, so that until a fairly high speed is reached the exciting current is negligeable. In this way a greater simplicity is realized and the scheme operates very satisfactorily.

The torque exerted during the first period of the starting operation may be considered as the combination of three separate torques, all resulting from induction motor action in different secondary circuits in the rotor. First, there is a torque developed in the squirrel-cage winding. This winding, when connected continuously from pole to pole, forms a relatively complete polyphase secondary, and its speed-torque curve is similar to that of an induction motor. By selecting the material and section of the bars embedded in the pole-faces, the form of the speed-torque curve may be controlled to cause the pull-out torque to be exerted at any given speed within certain limits. In the curves of Fig. 8, which are plotted from test results, this feature is clearly defined. In the second place, there is a torque due to eddy currents in the rotor and pole bodies. These currents flow mostly in the pole faces and in paths formed by the pole rivets. The paths have the effect of a high resistance damper winding not interconnected between poles. In addition, although not a true induction motor torque, there is a hysteresis torque which is produced by this iron loss of the rotor. The torque is small and constant in value. The third torque is produced by the closed field winding acting as a single-phase secondary. It is a characteristic tendency for the torque of a single-phase secondary to be reversed above one-half synchronous speed.*

*This article should be read in conjunction with the article on "Principles and Characteristics of Synchronous Motors" by the author in the JOURNAL for March, 1921, p. 87.

*See "Polyphase Induction Motor with Single-Phase Secondary" by B. G. Lamme in the JOURNAL for Sept., 1915, p. 394.

Therefore, above half speed the torque of the field winding is liable to be negligeable factor, although below this speed its effect is positive in direction. The curves, Fig. 8 show that the torque produced by the closed field winding is materially reduced above one-half synchronous speed. These tests were not carried below this speed with the field open; however, the results of other tests on the torque at standstill of a

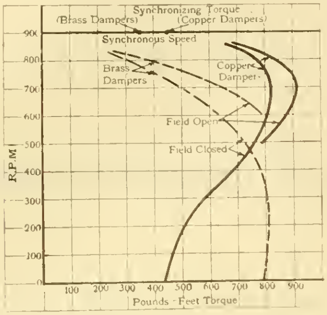

FIG. 8—SPEED-TORQUE CURVES OF A 225 HP SYNCHRONOUS MOTOR
Taken at approximately one half voltage.

similar motor under the same conditions are shown in Fig. 10. These curves show that the torque is reduced considerably when the field winding is closed, even though it produces a torque of positive direction. The reason for this reduction of torque may be stated somewhat as follows:—When the field circuit is closed it, being of low resistance, will tend to choke back the fluxes interlinking the damper winding, i. e. the useful flux. This shows itself as an increased component of primary reactive current and leakage flux. The torque produced by the main damper winding will consequently be reduced to such an extent that the relatively small torque exerted by the field winding will fail to compensate for this reduction. Thus, the net result is a decrease of the total torque of the rotor.

The same effect also results from the use of compound damper windings, but to a lesser degree. By compound damper windings is meant two sets of bars, or bars and end rings, on the same rotor, each set having a different resistance and reactance. In designing these windings, therefore, as in the case of a simple damper winding a compromise must be made: in the former case, to give the greatest variation of effective rotor resistance without increasing the leakage reactance too much; and in the latter case to proportion the effective rotor resistance to give the highest torque both at starting from rest and near synchronism.

Unless the load torque be too great, the combined induction torque should accelerate the rotor to within perhaps five percent of synchronous speed, where the rotor will remain and thus complete the first phase of the starting operation. Occasionally when a motor has reached this stage it will make the transition to synchronous operation without any further external adjustment, although ordinarily it is necessary to apply the field excitation because this will assist considerably in pulling the rotor into step. The torque exerted by the excitation fluctuates. It may be resolved into two components, one steady and the other alternating. The first may be explained by assuming the excited rotor to be driven by an external means from rest to synchronous speed. Thus the machine will be essentially a generator, inducing an e. m. f. in the armature winding, in proportion to its speed, which circulates a current at a corresponding frequency in the external circuit composed of transformers, supply lines and finally the windings of the actual generator at the other extremity of the line. This current will flow independently of the current of the impressed fequency, or what might be considered the driving current, but the two currents, when combined, will produce a single current which fluctuates in value at slip frequency. The magnitude of the fluctuation depends upon the amount of excitation. Under some conditions this phenomenon may be observed from the beating of the needle of the line ammeter. The torque produced by this generator action is represented by curve *IV* in Fig. 9. It is always a retarding torque and, near synchronous speed, may be regarded as practically constant in magnitude. An actual case has been recorded where a motor started under a heavy load and came up to within 5.5 percent of synchronous speed but would not synchronize; when approximately full excitation was applied the slip increased to 12.5 percent, due to the retarding torque; which instance shows that in some cases, at least, this effect will produce quite appreciable results.

The other component of torque due to excitation is that of ordinary synchronous action; that is, it is

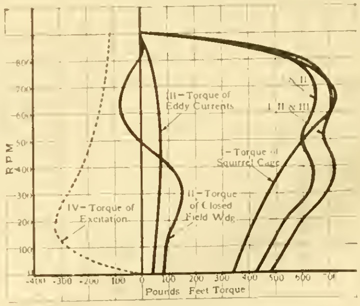

FIG. 9—STARTING CURVES OF A SYNCHRONOUS MOTOR

the result of the relative displacement between the rotor and the revolving armature field at any particular instant, according to the relationships expressed graphically by Fig. 3*. Throughout one-half the cycle of slip, the torque is positive, tending to keep the rotor in step, while throughout the next it is negative, tending to make the rotor slip behind at a still faster

*In the JOURNAL for March, '21, p. 89.

rate. Such a torque will set up forced oscillations of the rotor about the mean speed resulting from the combined steady torques, and these oscillations would continue indefinitely were it not for the fact that the alternating torque, when strong enough, will hold the rotor completely in step on one of its upward swings,

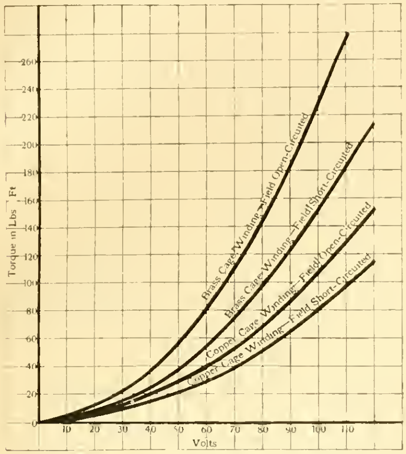

FIG. 10—TORQUES AT STANDSTILL OF 250 HP, 60 CYCLES, 440 VOLT, 600 R. P. M. SYNCHRONOUS MOTOR

whereupon the mean speed becomes synchronous speed. The alternating torque is a function of the excitation, which is also expressed by Fig. 3. The actual value required to pull the rotor into step depends upon several factors, such as the retarding torque of the applied load, and also the relation between the period of slip frequency and the inertia of the rotating masses. This latter point may be considered as follows:—The positive part of the torque acts in a series of impulses with a duration of one-half the period of slip frequency. For these impulses to pull the rotor into step, the retarding torque must be overcome and, in addition, an excess torque must be exerted to accelerate the rotating masses to synchronous speed in the half-period, or the duration of one of the positive impulses. Referring to Fig. 11, the synchronous torque curve for various rotor displacements is similar to those of Fig. 3. The difference between the load torque and the synchronous torque is that available for the acceleration of the rotor and load. The longer the period of slip frequency, or the less the inertia of the masses, the greater will be the increase of speed before the accelerating torque of a single impulse has fallen to zero. If the rotor has not been accelerated to synchronous speed before the displacement x is reached, the rotor will not synchronize and either the excitation or the applied voltage must be raised to increase the torque. If, however, as in Fig. 11, synchronous speed is reached at the displacement y, or less, the rotor will accelerate beyond synchronous speed momentarily and the forced oscillations of continuous slip will be replaced by free oscillations which, when damped out, leave the rotor at the point z and operating under stable synchronous conditions. The lower curve of Fig. 11 represents, with a simple assumptions, the relation between angular position and speed of the rotor when the latter synchronizes. It shows the oscillations of speed and displacement before the motor finally settles as at synchronous speed.

The synchronous torque due to the non-uniformity of the air-gap in salient-pole machines also exerts a torque assisting in the process of synchronizing, but as the actual value is ordinarily less than, and its duration only one-half that of the excitation torque, its effectiveness is much less and will actually perform the operation of synchronizing only in exceptional cases where the load and inertia are small.

The third step of the starting operation consists in changing over from the reduced starting voltage to the running voltage. The former varies from about 30 to 70 percent of the latter, and is obtained either by means of autotransformers used only for the purpose of starting; or, where a step-down transformer is required between the line and the motor, from starting taps.

When the starting switch is thrown from the starting position to the running position surges are almost inevitable. The case is somewhat similar to the synchronizing of two alternators, but has the disadvantage that the voltage and phase conditions of the motor are not under direct control at the instant of synchronizing, hence the resulting surges. The most serious surge ordinarily occurs at the instant of closing of the

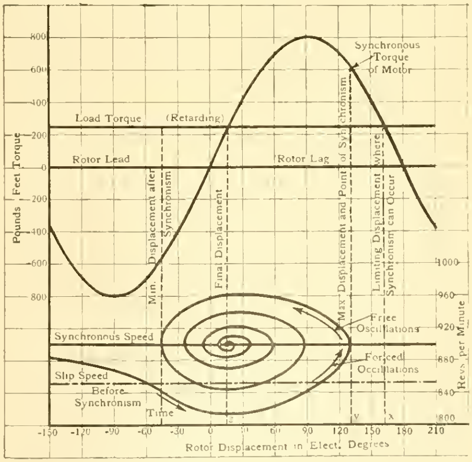

FIG. 11—SPEED AND DISPLACEMENT OSCILLATION OF SYNCHRONOUS MOTOR AT TRANSITION TO SYNCHRONOUS OPERATION

switch, due to an instantaneous difference between the voltage of the motor terminals and of the line, although there will probably be subsequent disturbances as the load is assumed again by the supply system.

As already stated, the equivalent flux of a motor is directly proportional to the applied voltage, so that

if the voltage be increased from 30 to 100 percent or from 70 to 100 percent, the flux must change in the same proportions. If the transition from one condition to the other were instantaneous, the resulting surges might be expected to be proportional to the increase of voltage. As a matter of fact, however, this is not necessarily true. In the case of small synchronous motors, the type of switching used allows a period of four or five cycles during which the connection between the motor and the line is entirely interrupted, although the transient conditions proceed in the motor. If, for instance, the motor be considerably over-excited when operating on the reduced voltage, the normal flux corresponding to this excitation will have been decreased by demagnetizing armature currents; but when these disappear on the interruption of the circuit, the flux will immediately begin to rise at a rate controlled by the damping effect of the rotor circuits, and the armature terminal voltage will rise correspondingly. This principle can be, and is, utilized to bring up the terminal voltage of the motor to meet that of the incoming line. The period of interruption is not long enough to allow the flux, and the voltage, to rise to what would otherwise be their final values, therefore, to reach the line voltage in the allotted time, the excitation must be set for an open-circuit voltage considerably in excess of the line voltage. If, for instance, the change-over be from 1100 volts to 2200 volts the excitation should be set for an open-circuit voltage of perhaps 3000, which might bring the terminal voltage of the motor to about 2200 volts as the switch is closed on the line side, and thus reduce the surge to a minimum. The actual value of excitation required for any particular case must be determined experimentally, although some such ratio as that indicated above may give quite satisfactory results.

When the change-over is made with an appreciable load on the motor, the rotor will have taken up a certain backward phase displacement with respect to the revolving field when operating on the reduced voltage. On this account there will be a difference of phase angle between the motor and line voltages when they are synchronized. The surge due to this cause cannot be reduced materially by adjusting the field current.

The first surge produced by an instantaneous difference of voltage will die away very quickly. If the motor be loaded, however, there will be additional surges involving the inertia effects of the rotor as it oscillates in coming to a new phase displacement. This surge will persist for a much longer period, and is the one ordinarily observed from the swinging of the line ammeter needle.

Fig. 12* represents test data on the relation between the maximum armature current reached on change-over, expressed as a function of the field current. It will be observed that the field current is an important factor in determining the severity of the surge.

When large motors are started, involving heavier circuit-breaking apparatus, the transition period may last a second or more. A motor cannot be completely taken off the line for this period without producing excessive surges. Therefore, to overcome the difficulty, the circuit is not completely opened, but the voltage is still maintained through resistances or reactances which, in the latter case, may be a part of the starting transformer winding. This arrangement does not necessarily result in surges that are correspondingly less than in the case of the simple starting arrangement when used with the smaller motors and, as a matter of fact, may produce greater surges because the voltage maintained on the machine prevents the armature voltage from rising during transition. It is, however, necessary for the larger machines, and lends itself readily to automatic starting control as well.

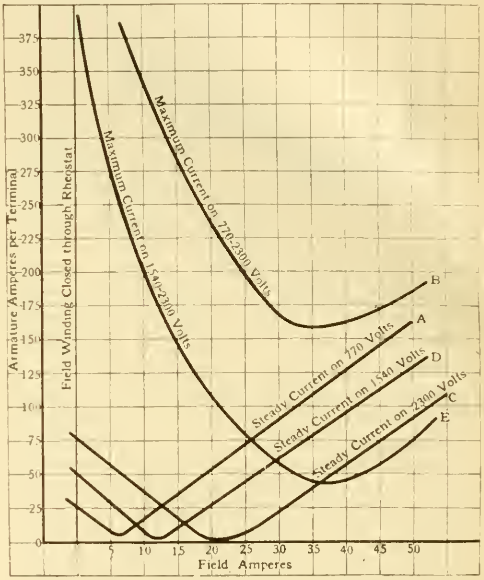

FIG. 12—RELATION BETWEEN ARMATURE CURRENTS AND FIELD CURRENTS OF 200 KV-A, 60 CYCLE, 2400 VOLT, SYNCHRONOUS CONDENSER

Maximum armature current reached on change-over expressed as a function of the field current.

As the synchronous motor is started on the induction motor principle its characteristics during the starting period may naturally be compared with those of the induction motor. In turning to the design proportions of these two types of machines, it will first be noted that the air-gap of the induction motor is much shorter and its number of slots is greater than that of the slots of a synchronous motor. The induction motor air-gap is made short to reduce the magnetizing current as much as possible, so that a high

*From "The Behavior of Synchronous Motors during starting"—F. D. Newbury, A. I. E. E., June 1913.

power factor may be maintained. On the other hand, the air-gap of a synchronous motor, is made wide enough to ensure inherent stability of operation under heavy loads. On starting, the result is that the synchronous motor draws a heavy magnetizing current and thus requires an increased kv-a input for a given voltage. Those phases magnetizing the inter-polar spaces will show especially heavy magnetizing currents.

Another effect of the wider air-gap is the increase of leakage reactance. The importance of this factor upon the torque is shown by the fact that the pull-out torque varies inversely as the leakage reactance. There are other causes of increased leakage in the synchronous motor; for instance, the concentration of the damper bars in the pole face and the decreased number of armature slots below what is considered a minimum for good induction motor design. This is especially true for machines with a large number of poles, i. e., slow-speed motors. In addition, as already mentioned, the closed field winding will increase the leakage reactance considerably, although the extra torque developed by it is small.

TABLE I—COMPARISON OF TORQUES AND KV-A AT STANDSTILL FOR 100 PERCENT VOLTAGE

	H.P.	R. P. M.	Percent Power-Factor	Percent Rated Torque	Percent Rated Kv-a
Slip-ring Induction Motor	300	900		200	350
Squirrel-Cage Induction Motor ..	300	900		125	675
Salient Pole Synchronous Motor .	300	900	100	175	750
Salient Pole Synchronous Motor .	300	900	80	200	700
Slip-ring Induction Motor	300	300		140	220
Squirrel-Cage Induction Motor ..	300	300		100	425
Salient Pole Synchronous Motor..	300	300	100	90	375
Salient Pole Synchronous Motor.	300	300	80	100	350

On comparing the synchronous motor with the squirrel-cage type of induction motor, the former has one distinct advantage; the damper winding can be designed from the standpoint of torque requirements alone. In the case of the squirrel-cage induction motor, the rotor losses at full load must be reduced to give high efficiency, so that a part of the torque at standstill must be sacrificed to obtain this.

The whole matter may be summed up by stating that, for starting, the synchronous motor is an imperfect form of induction motor, drawing heavy magnetizing currents and having a comparatively high leakage reactance. On the other hand, its winding, being designed for maximum torque regardless of efficiency, utilizes the remaining possibilities to the utmost, so that the actual torque becomes quite comparable to that of the induction motor, although the kv-a input is rather greater. To make this more definite, the values of torque and kv-a at rest are given in Table I, for corresponding motors at two different speeds. The falling off of torque for the slower speed motors is indicated by this table. The Table indicates, moreover, that the ratio of torque to the kv-a is higher for the synchronous motor than for the squirrel-cage induction motor. This is the result of the design concessions just referred to.

Cleaning Surface Condenser Tubes

D. W. R. MORGAN
Condenser Engineering Dept.,
Westinghouse Electric & Mfg. Company

MAINTAINING clean condensers is one of the most important items in the economical operation of the steam power plant. The best method to clean the condensers with a minimum expenditure is carefully studied by the larger power stations but is not, generally speaking, given proper consideration by stations having a relatively small output, probably due to the fact that, in such plants, less attention is paid to overall plant efficiency.

The degree of cleanliness at which the condenser is maintained, not only affects the B.t.u. heat transfer, which directly affects the vacuum, but also has a marked effect on the life of the tubes. The increased operating expense incurred, due to a discrepancy of 0.1 inch vacuum is given in Fig. 1. This curve shows the increased cost of operation at different loads, using a 25 000 kw unit as a basis, and assuming the cost of coal at $6.09 per gross ton. The curves in Fig 2. denotes the performance obtained after the condenser has been properly cleaned. A set of readings, shown in Table I, were obtained from the same condenser while in actual operation. In order to compare the performance obtained, with that expected, take the case for September 14th. With a circulating water temperature of 73 degrees the vacuum expected with a clean condenser is 28.05 inches, while that actually obtained is only 27.89 inches, showing a vacuum discrepancy of 0.19 inches, due to dirt and foreign matter coating the tubes.

The discrepancy between the vacuum obtained and that expected from a clean condenser is given in Fig. 3. It should be noted that the pressure difference between that obtained and that expected coincide from the 19th to the 22nd day of September. The way the curve falls off between the 22nd and 25th shows how rapidly the condenser fouls up.

It is the writer's opinion that the average condenser is not cleaned as often as it should be, nor is the cleaning as thorough as it might be. There are a few isolated cases where there is probably some excuse for this, but in the majority of cases it is based on an assumption which could not be substantiated by close examination of existing facts. For instance, a condenser serving a large turbogenerator unit may

not be taken off the line and thoroughly cleaned, due to the fact that the water rate of this machine is materially less than that of another unit, which would have to be placed in service, thus increasing the overall steam consumption of the station. If, however, the question of economy was thoroughly analyzed taking into consideration the permanent depreciation of the condenser tubes, due to the baking process, which permanently decreases the B.t.u. heat transfer of the tubes, it would not be difficult for the operating engineer to realize the advantages of giving the condensers a frequent and thorough cleaning.

TABLE I—PERFORMANCE OF CONDENSER DURING MONTH OF SEPTEMBER

Date	Load	Corrected Vacuum	Temperature Inlet Water	Temp. of Exhaust	Vac. Corr. to Temp. Exhaust
1	24 500	27.39	76	109	27.49
2	24 500	27.26	75	111	27.34
3	24 500	27.16	76	113	27.18
4	24 500	27.13	75	112	27.26
5	20 000	28.00	72	101	28.02
6	22 000	27.79	75	104	27.83
7	24 000	27.78	74	104	27.83
8	24 000	27.52	73	108	27.56
9	24 000	27.43	75	109	27.49
10	24 000	27.42	75	109	27.49
11	24 000	27.25	74	112	27.26
12	21 500	28.08	74	99	28.13
13	24 000	27.96	74	101	28.02
14	24 000	27.88	73	103	27.89
15	24 500	28.05	73	100	28.07
16	24 000	27.98	72	101	28.02
17	24 000	28.09	71	99	28.13
18	24 000	28.06	73	100	28.07
19	17 000	28.41	69	94	28.40
20	24 000	28.25	67	96	28.29
21	24 000	28.19	69	97	28.24
22	24 000	28.13	71	98	28.19
23	24 000	28.05	71	99	28.13
24	24 500	27.99	71	100	28.07
25	24 000	27.72	71	104	27.83
26	23 000	28.17	71	98	28.19
27	20 000	28.10	72	98	28.19
28	20 000	27.96	77	101	28.02
29	20 000	28.10	72	99	28.13
30	18 000	28.15	73	98	28.19

TYPES AND METHODS OF CLEANING

1—Rodding of condenser.
2—Wire brushes.
3—Application of cinders to the intake

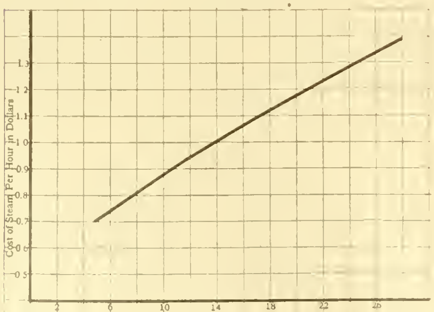

FIG. 1—LOSS DUE TO A DISCREPANCY OF 0.1 INCH VACUUM WITH A STANDARD 25 000 KW MACHINE

Assuming the cost of coal at $6.09 per gross ton.

4—Application of air or water pressure to condenser heads.
5—Rubber plugs.
6—Scraper type cleaners.
7—Reversal of flow of water.
8—Combination of air and water pressure.

The first method is probably the oldest and the most expensive. It consists merely of cleaning the tubes by using rods having practically the same diameter as the inside of the tubes.

The application of wire brushes is an expensive method and is only applicable in cases where the deposit is of a slimy nature and easily removed.

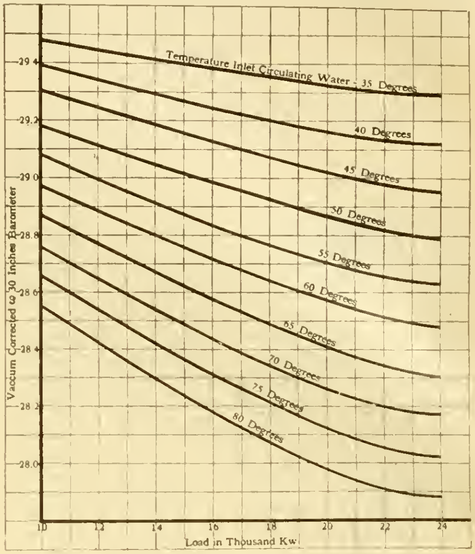

FIG. 2—PERFORMANCE CHART FOR SURFACE CONDENSERS

Vacuum to be expected with clean condenser.

The third method consists of applying cinders to the intake tunnel, allowing them to circulate through the water pump to the condenser head, thence through the condenser tubes. This method is probably the least expensive, but will only remove deposits of a very mild nature and incidentally is a source of trouble in case the cinders contain carbon, which will attack any foreign material that may be in the tubes.

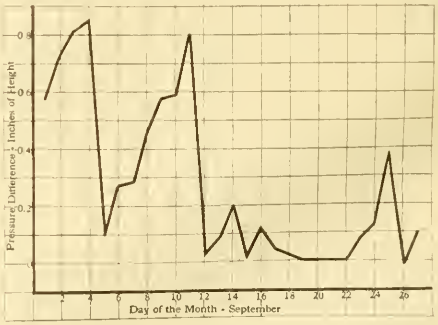

FIG. 3—DIFFERENCE BETWEEN VACUUM ACTUALLY OBTAINED AND VACUUM TO BE EXPECTED WITH CLEAN CONDENSER

In the fourth method, water or air is applied to the condenser head through connections made by a universal joint to an external source outside of the

water box. This method is applicable only where special provisions have been made on the manhole cover of the condenser heads. Although the process materially decreases the amount of debris that collects at the entrance of the tubes, it does not in any way decrease the deposit that may occur on the inside of the tubes. It is obvious that the universal joint and

FIG. 4—ADJUSTABLE RUBBER PLUG

FIG. 5—CLEANER OF THE SCRAPER TYPE

connection must be made at each end of the condenser, inasmuch as the cleaning process goes on at the same time that the condenser is in service and the pressure applied must be in the same direction as the flow of water through the condenser in order to eliminate any water hammer effect.

The fifth method is well adapted to clean the tubes when the deposit is of a slimy nature. The adjustable rubber plugs, Fig. 4, are inserted into the tubes and are driven through by compressed air or water pressure. The plugs are so designed that they will fit the tube snugly. Then the applied pressure and the resistence encountered, due to the deposit, causes them to bulge out, thus forming a very effective cleaning surface. The general method of using rubber plugs is to break the drain line in the rear of the condenser and install a perforated basket to catch the plugs as they reach the rear of the condenser. They are then taken to the front and shot through, over and over again. It is not necessary to remove the condenser heads unless the gases in the condenser are obnoxious, and even in such a case a small exhaust fan set up over one of the manholes in the rear of

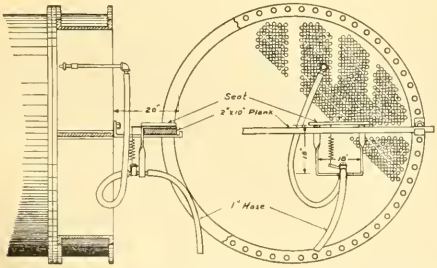

FIG. 6—ARRANGEMENT OF EQUIPMENT FOR CLEANING CONDENSER WHEN HEAD HAS BEEN REMOVED

the condenser will insure pure air for the men working in the front heads. In order to use the rubber plugs economically, it is advisable to use a number of plugs, equal to 25 percent of the total number of tubes in the condenser.

A cleaner of the scraper type, as shown in Fig. 5 is applied in a similar manner as the adjustable rubber plugs. This method of cleaning applies particularly to cases where there is a brittle or hard deposit on the tubes. The sketch in Fig. 6 illustrates the arrangement required for either the adjustable rubber plug or the cleaner of the scraper type, in cases where the condenser head has been removed. The brackets which support the scaffold plank are bolted to the flange of the condenser and may be set at any elevation. The seat and foot rest are made in one piece and can be moved along the plank to the most convenient position. A three-fourths inch quick opening gate valve is supported from the foot rest and is controlled by the operator's foot. Large condensers are cleaned without taking the heads off, this eliminates the seat and foot support, and the three-fourth inch valve is then located adjacent to the nozzle and is operated by hand.

The seventh method is to provide valves in the intake and discharge line of the condenser in order to reverse the flow of the water. The first cost of this ar-

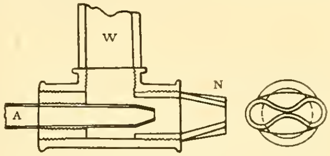

FIG. 7—EJECTOR FOR APPLYING LOW-PRESSURE WATER TO THE TUBES BY COMPRESSED AIR

rangement is high and it is doubtful whether the benefits derived are as satisfactory as those obtained by other schemes.

The eighth method consists of applying low pressure water and air at 80 pounds pressure to the tubes. The equipment, Fig. 7, consists of a three fourth inch T, into which the one-fourth inch air nozzle *A* is inserted, thus forming an ejector. Nozzle *N* is flattened out, as shown in the end view, so as to impart a spiral flow to the water. The air connection is made to point *A* and the water connection is made at *W*, using water at atmospheric pressure. It requires about five seconds to clean each tube properly with this method.

A mild solution of hydrochloric acid or caustic soda is sometimes used for cleaning condenser tubes. The solution is injected into the system, filled with water, which is then brought up to the boiling point. In most cases the use of chemicals, for cleaning tubes, causes rapid deterioration of the tubes.

The life of the condenser tubes will be materially increased in nearly all cases if proper consideration and methods are adopted to clean the condensers properly and periodically

Methods of Magnetic Testing

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An approximate determination of the magnetic properties of materials is relatively simple. However, there are so many methods available and so many kinds of magnetic materials, that the novice is often at a loss to choose the best and simplest method of testing. It is our purpose to give a resumé of the principal method, to point out the advantages and limitations and to show which are most suitable, as determined by the material to be tested, the accuracy desired and the speed which is necessary. For research work; where accurate fundamental data are sought one may be justified in using laborious methods and complicated apparatus. When routine acceptance tests are to be made on many samples a day, accuracy may be sacrificed for speed, reproducibility of results being the only essential.

TABLE I—UNITS OF INDUCTION

	Maxwells or Lines per Sq. In.	Kilo-Lines per Sq. In.	Lines per Sq. Cm.	Gausses	Kilo-Lines per Sq. Cm.	Kapp Lines per Sq. In.	Kapp Lines per Sq. Cm.
1 Line per sq. in.	1	0.001	0.155	0.155	0.000155	0.000167	0.0000258
1 Maxwell per sq. in.	1	0.001	0.155	0.155	0.000155	0.000167	0.0000258
1 Kiloline per sq. in.	1000	1	155	155	0.155	0.167	0.02584
1 Kilomaxwell per sq. in.	1000	1	155	155	0.155	0.167	0.02584
1 Line per sq. cm.	6.45	0.00645	1	1	0.001	0.001075	0.000167
1 Maxwell per sq. cm.	6.45	0.00645	1	1	0.001	0.001075	0.000167
1 Gauss	6.45	0.00645	1	1	0.001	0.001075	0.000167
1 Kiloline per sq. cm.	6450	6.45	1000	1000	1	1.075	0.1667
1 Kilomaxwell per sq. cm.	6450	6.45	1000	1000	1	1.075	0.1667
1 Kilogauss	6450	6.45	1000	1000	1	1.075	0.1667
1 Kapp Line per sq. in.	6000	6	930	930	0.93	1	0.155
1 Kapp Line per sq. cm.	38 700	38.7	6000	6000	6	6.45	1

MAGNETIC PROPERTIES

The chief magnetic properties of interest to the engineer are normal induction, hysteresis characteristics and eddy current losses. The normal induction data (which are actually the locus of the tips of a series of hysteresis loops) may be expressed in a variety of ways, but usually they are given as the values of the magnetizing force H, Fig. 1, for definite values of induction.

Various units are used for induction as indicated in Table 1. Most scientific data are expressed in gausses or kilo-gausses. The majority of the designers in this country use lines per square inch.

In scientific literature, the term intensity of magnetization I also appears, where,—

$$I = \frac{B\ H}{4\ \pi}$$

The engineer uses this term very little. Occasionally the term ferric induction B_o is used which is equal to BH or $4\ \pi\ I$ and gives the increased magnetic induction due to the presence of magnetic material. It is obvious that B increases indefinitely with H, but B_o and I reach a definite limiting value called saturation, which corresponds to the point where the molecular magnets all become parallel. The magnetizing forces are expressed in various units as shown by Table II.

Gilberts per centimeter and gausses are identical, the latter term having been adopted recently as the unit of magnetizing force. The reason for adopting the gauss as a unit of magnetizing force as well as induction is that in air a magnetizing force of one gilbert per centimeter produces an induction of one line per square centimeter, which is equal to one gauss. Most scientific data are expressed in one of these terms. In this country the designer generally uses ampere-turns per inch.

It is often convenient to express the normal induction data in terms of permeability, either for a given induction or a given magnetizing force, where permeability,—

$$\mu = \frac{B}{H},$$

when B and H are expressed in gausses.

A μH curve is shown in Fig. 1. The maximum permeability μ_m maybe determined from the B-H curve by drawing a tangent to this curve passing through the origin. At the point of tangency $\mu_m = \frac{B}{H}$

TABLE II—UNITS OF MAGNETIZING FORCE

	Gilbert per Cm.	Gausses	Amp-Turns per Cm.	Amp-Turns per In.
1 Gil. per cm.	1	1	0.796	2.02
1 Gauss	1	1	0.796	2.02
1 Amp-turn per cm.	1.255	1.255	1	2.54
1 Amp-turn per in.	0.495	0.495	0.394	1

Normal induction data are of interest to the designer chiefly as they enable him to determine the number of turns and the magnetizing current necessary to bring his iron circuit up to the desired induction.

For many purposes the data obtained from the hysteresis loop, Fig. 2, are of primary importance. The chief characteristics of the hysteresis loop are the maximum induction B_m for a given magnetizing force or the maximum magnetizing force H_m for a given in-

duction, the retentivity B_r, the coercive force H_c and the hysteresis loss as determined from the area of the loop. B_m, B_r and H_c are of chief interest in connection with such materials as permanent magnet stock or cores for solenoids. The hysteresis loss is of interest

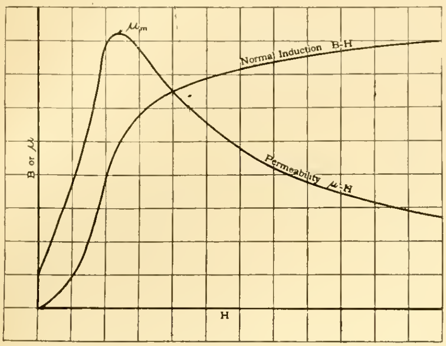

FIG. 1—NORMAL INDUCTION AND PERMEABILITY CURVES

when the material is subjected to alternating flux, as for instance the cores of transformers, motors, generators, etc.

DIRECT-CURRENT TEST METHODS

There is, in general, no difficulty in measuring induction with considerable accuracy. It is only in a few types of magnetic circuit, however, that the magnetizing force can be readily measured with any reasonable degree of accuracy.

METHODS OF MEASURING INDUCTION

The methods of measuring induction may be divided into the following classes:—

1—Magnetometric
2—Traction
3—Deflecting Coil
4—Rotating Coil
5—Bismuth Spiral
6—Polarized Light
7—Ballistic or Flux-meter
8—Volt-second Meter

1—*The magnetometric method* is one of the classical methods used for much of the early magnetic work.[1] If a long sample of magnetic material is magnetized longitudinally, magnetic poles are generated which may be caused to act on a compass needle or magnetometer. Knowing the constants of the magnetic needle, its distance from the sample, and the value of the magnetic field normally acting on it, the induction in the sample may be calculated.

2—*The traction method* of measuring induction is based on the fact that the magnetic pull beween two pieces of magnetized material is proportional to the square of the induction.

3—*The deflection of* a D'Arsonval meter movement is proportional to the current flowing in its coil and to the strength of the magnetic field in which it moves. If such an element forms a part of a magnetic circuit and the current through the moving coil is kept constant, the deflection of the coil will be proportional to the flux in the magnetic circuit.

4—If a coil with its axis at right angles to a magnetic field is caused to rotate at a definite speed, a voltage will be generated in it which may be read by means of a suitable voltmeter, and this voltage will be proportional to the flux threading the rotating coil.

5—*If a piece of bismuth wire coiled* up in a convenient form, such as a spiral, is placed in a magnetic field, its electrical resistance will change due to the field, and this change will be a function of the intensity of the magnetic field. By the use of a suitable bridge and calibration for the bismuth, magnetic field strengths may be readily determined.

6—*If a beam of polarized light* be reflected from a magnetized surface its angle of polarization will be shifted. The angle of shift is a function of the magnetic intensity at the surface of the metal and may be measured in the usual way by means of Nicol prisms.

7—*The ballistic method* is perhaps the simplest and most used method for measuring induction. If a magnetized sample is surrounded by a coil of wire connected to a ballistic galvanometer or flux-meter*, and the flux in the sample is caused to change, or the coil is suddenly removed from the sample, the galvanometer or flux-meter will be deflected and this deflection is a measure of the change of flux threading the coil.

8—If a coil of wire surrounds a magnetized circuit and the magnetic flux is changed, this change of flux is proportional to the $\int e\,dt$ where e is the voltage generated in the coil. If an integrating voltmeter or volt-second meter is connected to such a coil, the reading of this meter will be proportional to the change of flux. There is no essential difference between the use of a flux-meter and a volt-second meter, except that the flux-meter can rotate only a fraction of a revolution whereas the volt-second meter can rotate as many revolutions as desired.

METHODS OF MEASURING MAGNETIZING FORCES

The methods of measuring magnetizing forces are as follows:—

a—Long solenoid.
b—Solenoid with ellipsoid sample
c—Concentric air coils.
d—Magnetic potential coil.
e—Completely closed ferro-magnetic circuit with magnetizing coil.
f—Compensation methods.

a—If a long, uniformly-wound solenoid carries a known current the magnetizing force at its center will be expressed as follows:—

$$H = \frac{0.4\,\pi\,NI}{L} \qquad (1)$$

Where H is in gilberts per centimeter or gausses,
N is the total number of turns in the coil,
I is in amperes,
L is the length of the solenoid in centimeters.

If this solenoid contains an iron sample whose length is several hundred times its diameter this formula will still hold.

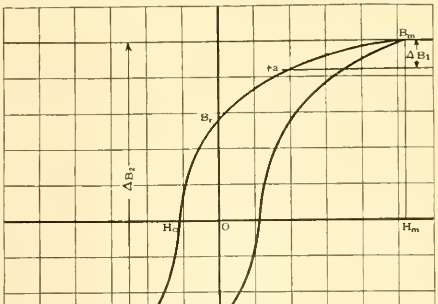

FIG. 2—HYSTERESIS LOOP

b—If the sample in the above mentioned solenoid is shorter, the ends will exert an appreciable demagnetizing effect, and the effective magnetizing force will be less than that calculated by formula (1). If the sample is in the form of an ellipsoid this

*A ballistic galvanometer differs from an ordinary D'Arsonval galvanometer only in having a long natural period. A flux-meter is a ballistic galvanometer which has very little restoring torque and which is very much overdamped electromagnetically, i. e., is used in a very low resistance circuit. For a discussion of the characteristics of ballistic galvanometers and flux-meters see Law's "Electrical Measurements", or Leeds & Northup Co. Philadelphia, Pa., catalog on moving coil galvanometers.

demagnetizing effect may be calculated by means of the demagnetizing factors given by Ewing.[2] If the sample is in the form of a cylindrical rod, these same factors may be used without much error. The ellipsoid is the only form of bar sample for which the demagnetizing factors can be readily calculated, due to the fact that in such a sample the lines of induction are parallel.

c—If a straight magnetized bar is surrounded by a pair of concentric helical coils having an equal number of turns, and these coils are connected differentially to a ballistic galvanometer, we have a means of measuring approximately the magnetizing force *H*, by observing the galvanometer deflection when the flux through the bar is reversed. Such a pair of coils may be calibrated by placing them in a long solenoid of known constants with axes parallel, and reversing the current in the solenoid. Or the constants may be calculated from the number of turns and dimensions.

d—By means described by Rogowski and Steinhaus[3], and others, we may measure the magnetic potential directly between any two points. The method consists in winding uniformly many turns of fine wire on a thin flexible strip of nonconducting material, placing the coil in a known, long solenoid, and noting the ballistic throw of a galvanometer connected to the coil when the solenoid current is reversed. Knowing the constants of this coil, or magnetic potential meter, all that is necessary is to apply its two ends to two points on a magnetic circuit, reverse or reduce the flux in the magnetic circuit and note the deflection of the ballistic galvanometer connected to the coil. This will give a direct measure of the change of magnetic potential between the two points, if no magnetic potential is generated by the coils or otherwise between two points.

e—If we have a completely closed ferromagnetic circuit surrounded by a uniform number of turns of wire per unit length of magnetic material, of which the simplest case is the ring, formula (1) may be applied directly to calculate the magnetizing force from the magnetizing current, provided the radial width of the ring is several times the diameter.[4] If an air-gap occurs in the magnetic circuit or a change of cross-section or material, or if the coil is concentrated, the calculation of the magnetizing force then becomes difficult and more or less uncertain.

f—If the reluctance of the joints and the yokes of a magnetic circuit can be compensated for by supplying just sufficient magnetomotive force by means of auxiliary magnetizing coils, then formula (1) may be applied directly to the main magnetizing coils for determining *H*.

APPLICATIONS

The magnetometric method of measuring induction (1) must obviously make use of methods *a* or *b* (long solenoid) for measuring *H*. Very complete descriptions of the method may be obtained from Ewing or almost any text book of physics. The method has the following disadvantages.

1—It is very suspectible to outside influences such as trolley lines, movable pieces of iron, etc.

2—Difficulty of obtaining the required samples in the form of long thin uniform rods or of machining shorter samples in the shape of ellipsoides.

3—The complication that for any but very long samples the true value of *H* is a function of *B*, thus requiring calculations.

The magnetometric method has two advantages; 1st, it is an absolute method capable of giving correct results from the dimensions and constants of the apparatus; and 2nd, it is very sensitive.

The traction method of measuring induction (2) is best exemplified in the Thompson permeameter[5], and the DuBois permeameter[6]. In the former, the induction is measured by noting the pull when the sample is pulled away from the yoke. In the DeBois permeameter, the upper part of the yoke is separated from the lower by two air-gaps and is supported by knife edges. The unbalanced magnetic pull is counteracted by sliding weights. The magnetizing force is measured from the current in the magnetizing coils which in both cases surround the samples. In neither type of apparatus can *H* be calculated accurately and it can be determined only by calibrating the apparatus with known samples, standardized by some absolute method. The correction varies with each type of material and in the Thompson instrument with the condition of the contact surface, friction between the sample and yoke, etc. These traction methods are not capable of high accuracy and are very little used today, though they may find some application when a large number of samples of similar material are to be compared.

Method 3, using a deflecting coil for measuring induction is best illustrated by the well known Koepsel permeameter, which is similar to a D'Arsonval type of direct-current meter with the difference that a constant current is maintained in the moving coil, the permanent magnet is replaced by massive yokes, and the sample to be measured is surrounded by a magnetizing coil. A very complete description of the apparatus is given by the Bureau of Standards,[7] together with a discussion of the accuracy. The magnetizing forces with suitable corrections, method *e*, are determined from the current in the magnetizing coil surrounding the sample. This apparatus has the advantage that *B* and *H* may be made direct reading, but the disadvantage that a different correction to the value of *H* must be applied for each different kind of magnetic material tested. For the determination of the properties of a large number of samples of similar material, however, it is very convenient especially if the material has comparatively low maximum permeability. This type of apparatus has been used very extensively in the past.

Method 4, using the rotating coil, is well illustrated by the Esterline permeameter[8], which is very similar to the Koepsel except that the D'Arsonval movement is replaced by a direct current armature with the commutator driven by a direct-current motor coupled to a magneto. In determining *H*, an attempt is made to use method *f* by means of compensating coils on the poles. When there is no leakage from the ends of the samples, as determined by a magnetometer needle placed close to one end, it is assumed that the compensation is correct. This apparatus reads *B*, *H* and the speed of the rotating armature directly on a single meter by means of transfer switches. It is more complicated than the Koepsel apparatus and according to tests carried on by the Bureau of Standards some years ago[9] has no greater accuracy. Errors in *H*, unless corrected by using standard samples, are fifty percent or more in some cases, for ordinary magnetic materials.

The rotating coil method of determining flux has been used to advantage lately by Dellenbaugh[10] to measure the flux in the air-gap of rotating machines. This seems to be a very quick and satisfactory method.

The bismuth spiral method 5, is used only occasionally in experimental work, and has the disadvantage that the temperature compensation must be very carefully watched.

The polarized light[11] method, 6. has very little application as a test method. It is chiefly of scientific interest and can be applied readily only for high inductions.

The ballistic method, 7, of determining *B* is by far the most common one used, and lies at the foundation of the three most convenient and accurate methods of determining direct-current magnetic properties which we have available at present, namely, the ring test, the Fahy permeameter and the Burrows permeameter. Due to their very decided advantages these three types of test will be considered in considerable detail, both as to operation and accuracy.*

RING TEST

The ring test is well known and has been widely used in the past. Its method of operation is similar to that followed for the Burrows and Fahy apparatus to be described later. By following the modifications suggested most of the limitations considered formerly to be inherent in the ring test may be eliminated. The ring test is the simplest method available for obtaining magnetic data with a high degree of absolute accuracy.

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*A few other types of permeameters using the ballistic method for measuring *B* may be mentioned. In the Hopkinson divided bar method[13] the sample consists of two bars which are butted together and inserted in a massive frame or yoke. A magnetizing coil surrounds each of the sample bars. A small exploring coil, between the magnetizing coils, is placed over the butt joint and connected to a ballistic galvanometer. When one of the test bars is pulled out, the exploring coil is jerked out from the yokes by means of a spring, and the induction existing in the sample is given by the deflection of the ballistic galvanometer. *H* is determined from the current in the magnetizing coil. Obviously *H* cannot be calculated accurately, but may be determined roughly by calibrating the apparatus with known material. Also the effective value of *H* is a function of the condition of the air-gaps. This apparatus is now practically obsolete.

Another well-known type of ballistic test is the Ewing double-bar method[12]. Ewing undertook to overcome the disadvantage of the yoke and joint reluctance by using two bars machined to fit closely in two yokes. He first measured the

Fig. 3 shows the diagram of connections for a simple ring testing arrangement, when several samples are to be tested at once. The ring samples T_1, T_2 and T_3 are wound with primary and secondary windings, shown by the heavy and light lines respectively. The primary windings are connected in series through the reversing switch S_1 which reverses the main magnetizing current from the battery B_1 through the ammeter A_1, rheostats R_2 and R_3 and short-circuiting switch S_3. The rheostats R_2 and R_3 each have two contact arms which are insulated from each other; R_2, having low resistance, is used for fine adjustment, and R_3 having high resistance, is used for coarse adjustment of the magnetizing current. The secondary coils of the samples are connected through a selector switch S_4 to the secondary of the mutual inductance MI and the ballistic galvanometer G. The primary of the mutual inductance is supplied from the battery B_2 through the ammeter A_2 and the reversing switch S_2.

In order to calibrate the ballistic galvanometer, the ammeter A_2 may be set at one ampere, S_2 reversed and R_1 and R_2 adjusted until the ballistic galvanometer reads 10 centimeters. Now if

$$N_2 A = 10\, M\, I \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

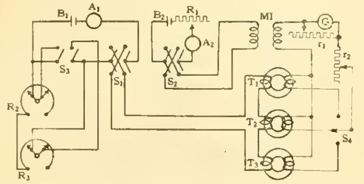

FIG. 3—DIAGRAM OF CONNECTIONS FOR A SIMPLE RING TESTING APPARATUS

where N_2 equals the secondary turns on each sample, A equals the cross section of sample in square centimeters, and MI equals the value of the mutual inductance, in millihenries, then when S_1 is reversed, one centimeter deflection of the galvanometer will correspond to one kilogauss of induction for the normal induction curve. H may be calculated for the sample from equation (1), where L is the mean circumference in centimeters. If N_1, the primary turns on the sample, are of such a number that H equals I, then H may be read directly from the ammeter reading. By using suitable shunts and a millivolt-meter, H may be made direct reading for any convenient number of primary turns.

In order to obtain a magnetization curve on the samples, ammeter A_1, is set for a definite value of H, switch S_4 is connected to the secondary of sample T_1, and S_1 is reversed. The galvanometer deflection in centimeters gives B in kilogausses for sample T_1. Switch S_4 is then turned to sample T_2, switch S_1 is again reversed and the corresponding galvanometer deflection gives B for sample T_2. After obtaining B for all of the samples at a given H, A_1 is increased to another value and the process repeated, thus obtaining a magnetization curve for each sample with a minimum amount of labor and no calculations after obtaining the data. If desired the galvanometer need not be calibrated, but a null method may be used by reversing switches S_1 and S_2 simultaneously and adjusting A_2 until there is no residual deflection of the galvanometer. By using suitable constants B can be made numerically equal to the current as measured by A_2; or again instead of varying A_2 it may be held constant and a variable mutual inductance used which is changed until there is a balance when S_1 and S_2 are reversed simultaneously. In this case,—

$$B = \frac{M \times 10^3}{N_2 A} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where M is the mutual inductance in millihenries, N_2 is the number of secondary turns on the sample, and A is the cross section in square centimeters. This formula is correct for one ampere in the primary of the mutual inductance. For any other current, of course, a suitable constant must be applied. By this means very high sensitivity may be obtained.

To obtain the hysteresis loops, the most accurate and satisfactory method is to refer each point to the tip value of the loop. After putting the sample into the cyclic condition by repeated reversals for the desired maximum induction or maximum H value, switch S_3 is opened, thus introducing resistance into the magnetizing circuit corresponding to the amount of resistance included between the two contact points of each rheostat R_2 and R_3. The corresponding deflection of galvanometer gives ΔB. (See Fig. 2, point a.) B on the hysteresis loop then equals $B_m - \Delta B$.

Unless the galvanometer has been calibrated for double the sensitivity used for the magnetization curve the reading must be multiplied by 2 to give ΔB in kilogausses. After obtaining point a, it is usually convenient to obtain point $-a$ having a negative value of H equal to the positive value a, by returning to the tip of the loop followed by suitable reversals, and then throwing switches S_1 and S_2 down simultaneously. This reduces H and also reverses it. Again,

$$B_{-a} = B_m - \Delta B \text{ (algebraically).}$$

By moving the right hand contact points of the

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magnetic properties with the yokes in one position and then increased their distance apart by some definite amount, say double, and made a new measurement of the magnetic properties. Obviously if the reluctance of the joints was the same in both cases the difference in magnetizing force between the first case and the second for a given induction was due to the reluctance of the extra length of the sample, and thus gave a means of correcting for the yoke reluctance. This method has the disadvantages that the joint reluctances and leakage conditions are never quite the same for the two positions, that two carefully machined duplicate uniform samples are required, and two sets of data must be determined.

Another ingenious permeameter depending on ballistic methods is the Picout[13], which uses a novel method of compensating for the reluctance of the yokes. This method is fully described and illustrated in the references. Burrows[7] has shown that this apparatus is subject to errors at the higher inductions. Moreover, the operation is somewhat tedious.

The volt-second meter method[14] 8, of measuring induction has its chief application in measuring the magnetic properties of transformer cores where even slow changes of magnetizing force will generate quite appreciable voltages. It makes a ready method of investigating the quality of transformer cores (the only source of current required being a storage battery) when it is desired to eliminate the disturbing effect of eddy currents.

rheostats, as many points on the hysteresis loop as de-desired may be obtained by the above proces.

In another article[15], the author has described in greater detail a more elaborate form of this apparatus. The labor of winding the samples is greatly reduced by using small rings (often only one inch in outside diameter), a few turns of large wire for the magnetizing coil and a few secondary turns of small wire. The small sample and a few secondary turns are made possible by using a very sensitive ballistic galvanometer. By immersing the samples in oil, as high as 100 amperes may be used on the primary for short intervals without serious heating, thus making it possible with a single layer winding to go to magnetizing forces of 300 gilberts per centimeter. By the use of ten samples connected in series it is possible to obtain complete 14 point magnetization curves in 4.5 minutes per ring and ten points hysteresis loops in six minutes. It requires less than ten minutes to wind each sample. For experimental work the samples may often be prepared simply and cheaply by rolling the material into sheets and punching rings with a compound die. If the radial width of the sample is small with reference to the diameter, an appreciable error may be introduced[4]. If the radial width is not more than one-eighth the diameter, however, the errors due to this effect are practically negligible.

The ring method as described above has the following advantages:—

1—High accuracy.

2—High speed.

3—A considerable number of samples may be obtained from one small ingot and be given various heat treatments.

4—By rolling and punching the material the cost of preparing the samples is very little.

The limitations are as follows:—

1—Small samples must be annealed before testing to remove punching or machining strains.

2—If large samples are used the expense of winding is prohibitive for commercial tests.

3—Some materials like permanent magnet steel and Epstein strips, prepared for core loss tests, require for test a permeameter taking straight strips or bars.

FAHY PERMEAMETERS

Two new permeameters have recently appeared on the market devised by Mr. Frank P. Fahy and known respectively as the Fahy duplex and the simplex permeameters. These instruments use the ballistic method 7 for measuring B, and the magnetic potential method c for measuring H. A complete description of the Duplex instrument is given by the Bureau of Standards[9]. The Duplex instrument may be used to give a comparison between a standard sample and an unknown or, if desired, a single sample may be used and results obtained by what is called the absolute method. Fig. 4 shows the essentials of the duplex apparatus, together with the internal connections. The magnetic yoke is in the form of an H with a standard sample A and the unknown X placed as shown by the dotted lines. The magnetizing coil M sends flux around the two circuits of the permeameters through the two samples as indicated by the arrows. In general, due to differences in the samples, these fluxes will be different. In order to make the magnetic potential for the two samples equal, the two secondary coils, T, D,D' and S, all having the same number of turns, are connected in series with a ballistic galvanometer so that the induced e.m.f. in coils S and D' are in the same direction, but opposite to that generated in T and D. The compensating coils C are supplied from the same battery as M, but through separate reversing switches and control resistances. If, now, the currents in M and in C are reversed simultaneously and the compensating current adjusted so that there is no residual deflection of the galvanometer, the leakage fluxes for two magnetic circuits of the permeameter will be balanced and the same magnetizing force will be applied to the samples. Then by connecting T and S successively to the ballistic galvanometer, which is calibrated in the usual way with a mutual inductance, the values of B for the two samples may be read. From the known B-H curve for the standard sample, H is known for the X sample.

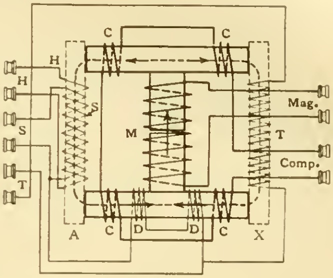

FIG. 4—ELECTRICAL CONNECTIONS OF THE FAHY DUPLEX PERMEAMETER

In order to test a single bar by the absolute method, the sample is placed in T. The procedure is the same as for the comparison test except that the magnetizing force is read by connecting the air coil H to the ballistic galvanometer. This coil has a large number of turns and measures the difference in magnetic potential between the yokes or when the apparatus is compensated gives the value of H as applied to the sample X in coil T. The principle of operation for measuring H and determining hysteresis data is the same as that to be described for the simplex apparatus below.

The simplex permeameter is arranged as shown in Fig. 5. The center of the iron yoke Y is supplied with a magnetizing winding M. The sample is located at X as shown by the dotted lines and is surrounded by a test coil T. Two iron posts PP are clamped against the sample and carry between them the air coil H, consisting of several thousand turns of fine wire. When coil T is connected to a ballistic galvanometer and the current in M is reversed the galvanometer deflection will give B, which may be made direct reading as for the ring test described above by suitable calibration

with a mutual inductance. If the galvanometer is next connected to coil H, the magnetizing force may be similarly determined from the deflection when M is reversed. The method of obtaining H is the magnetic potential coil method d described above.

For hysteresis data B is determined by first measuring ΔB by introducing resistance into the magnetic circuit and subtracting ΔB from B_m. (See description of ring test.) H may be determined similarly by first measuring ΔH and subtracting it from H_m, or if the instructions issued with the apparatus are followed H is measured by reducing the induction to the desired value and determining H directly from the galvanometer throw when connected to the H coil by decreasing the magnetizing current to zero. This procedure will be in error if the yokes have any appreciable residual induction.

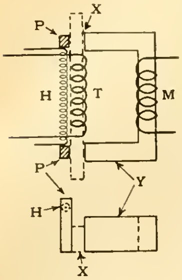

FIG. 5—CONNECTIONS OF THE FAHY SIMPLEX PERMEAMETER

The simplex apparatus is simple and easy to use and is especially suitable for permanent magnet steel testing. The duplex is very nearly as complicated as the Burrows apparatus and probably is slightly less reliable. When comparisons are required, however, between a standard and unknown samples, the duplex apparatus should have quite a field of usefulness.

BURROWS PERMEAMETER

The Burrows permeameter[16], within its field, is considered the most accurate instrument available for magnetic testing. B is measured by the ballistic method 7 and H is determined by a compensating method f. The essential magnetic and electrical circuits are shown by Fig. 6. For this test two bars or sheet samples M_1 and M_2 are required which are placed in the yokes YY as indicated, M_1 being the sample under test. The primary windings are shown above the samples and the secondary below. The magnetizing winding T for the sample M_1 extends the whole distance between the yokes. On top of this, at the ends, are placed the compensating windings J_1J_1. Similarly windings A and J_2J_2 surround sample M_2. Underneath the primary windings close to the samples are the secondary windings as shown by the fine lines. t is placed at the center of sample M_1 and a at the center of M_2. j_1 and j_2 are placed about half way between the centers and ends of the sample and each has one half the number of turns of t and a. The function of the compensating coils J_1J_1 is to supply enough magnetomotive-force to take care of the reluctance of the joints and yokes. That this condition is satisfied is determined by means of coils j_1j_1 which must be threaded by the same flux as t, namely, there must be no leakage.

The procedure is as follows. Battery B_1 supplies current to the magnetizing coils T and A through the reversing switches S_1 and S_2 which are operated together. Compensating coils J_1 and J_2 are supplied by battery B_2 through switch S_3. If now S_1 and S_2 are reversed simultaneously, there will be produced in general a deflection of the galvanometer G if switch S_5 is set so that a and t are connected opposing (position 2). This means that the fluxes in M_1 and M_2 are not identical. By adjusting R_1 or R_2 these fluxes may be made the same. Now connect t and j_1j_1 in series opposing by means of switch S_5, (position 1) and reverse S_1 and S_2 simultaneously. If the flux in M_1 is not uniform there will be a deflection of the galvanometer. By adjusting R_3 this may be reduced to a residual deflection of o. In general, it will be necessary to readjust for equality of t and a. Having made this adjustment the procedure is exactly similar to that followed for the ring test. By throwing S_5 to the mutual induction position 3, the galvanometer may be calibrated to read B directly or a null method may be used by varying the mutual inductance primary current or the mutual inductance itself and reversing S_4 simultaneously with S_1, S_2 and S_3. In order to obtain the hysteresis loops, resistances (not shown) are introduced into the magnetizing and compensating circuits by suitable switches and the usual compensations made. By the use of a suitable gang switch these operations may be made quite simple. H is calclated from the constants of the primary coil T by formula (1), and B from the turns of t and formula (2).

The operation may be considerably simplified if two samples sufficiently alike are available so that they may be tested for the mean value of the two. In this case two more secondary compensating coils j_2j_2 similar to j_1j_1 are placed over sample M_2 and connected perma-

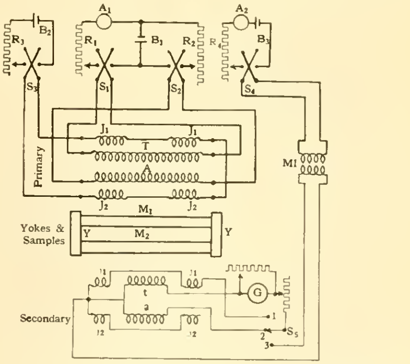

FIG. 6—MAGNETIC AND ELECTRICAL CIRCUITS OF THE BURROWS PERMEAMETER

nently in series with j_1j_1; also A and T are connected permanently in series and also a and t. Tests for equality between M_1 and M_2 may now be omitted. This procedure corresponds to that recommended by the American Society for Testing Materials[17]. This will be called the A. S. T. M. test and the former the precision test.

Fig. 7 shows the primary connections of the Burrows testing table as used by the Westinghouse Research Laboratory and Fig. 8 the secondary connections. The apparatus is arranged for null or deflection methods of test by the precision or A. S. T. M. method and for testing ring samples. The primary

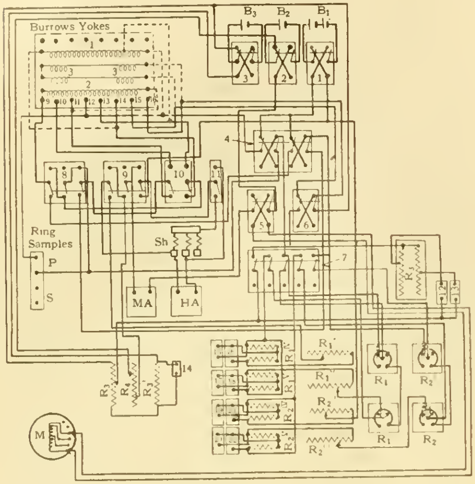

FIG. 7—PRIMARY CONNECTIONS OF THE BURROWS TESTING TABLE

switches are operated by means of foot levers, leaving the operator's hands free for recording data and changing the secondary switches. The primary ammeters and shunts are so arranged that H is read directly. Two types of yokes are used, one for round samples and the other for rectangular bars or sheet material of standard Epstein size, 3 cm. wide. The

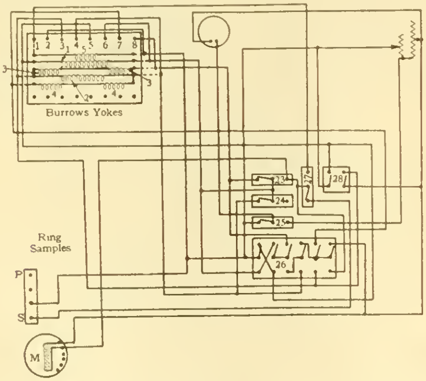

FIG. 8—SECONDARY CONNECTIONS OF THE BURROWS TESTING TABLE

flux enters the edge of the sheet or bar samples. The magnetic circuit is shown by Fig. 9 for these yokes The method of introducing resistance for the hysteresis loops is similar to that used for the ring test described above, namely, using two taps on a rheostat and opening a short circuit between. No detailed description of the circuits will be given as a person familiar with the Burrows test can easily trace them out.

The operation of the Burrows apparatus, especially for the precision method, is rather complicated and tedious, but due to its accuracy for commercial materials these disadvantages may often be ignored.

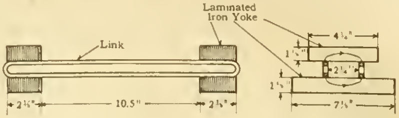

FIG. 9—MAGNETIC CIRCUIT OF BURROWS PERMEAMETER

When the A. S. T. M. method of test is used, and there is no difficulty in providing two samples alike, as for instance Epstein strips, the operation is not especially difficult. For routine tests for permeability, at say three inductions per sample, with a suitable correction curve for variations in the weight of samples, an experienced operator can test one hundred samples per day. When reduced to its simplest forms for such permeability tests, a non-technical man may be taught in a very short time to operate the apparatus successfully. By the use of a variable mutual inductance, which may be set to a value corresponding to the inductions desired as determined by the weight of the sample and using a null method, no galvonometer calibrations are required.

REFERENCES

[1]"Magnetic Induction in Iron and Other Metals" by J. A. Ewing.

[2]Ewing, p. 31.

[3]Rogowski & Steinhaus: *Archiv fur Elektrotechnick*, I, p. 141 (1912).

[4]"Errors in Magnetic Testing with Ring Specimens" by M. G. Lloyd. *Bulletin Bureau of Standards*, Vol. V, p. 435, (1908-9).

[5]Ewing, p. 259; *American Handbook for Elec. Engr.*, p. 918; *Standard Handbook for Elec. Eng.* p, 188.

[6]Ewing, p. 374; *American Handbook for Elec. Engr.*, p. 919.

[7]"An Experimental Study of the Koepsel Permeameter" by Chas. W. Burrows. *Scientific Paper. No. 227, Bureau of Standards*, August 1914; *American Handbook for Elec. Engrs.*, p. 919 *Standard Handbook for Elec. Engrs.*, p. 188.

[8]J W. Esterline—*Transactions* A. S. T. M. Vol III, p. 288, (1903); Vol. VIII, p. 190, (1908). *American Handbook for Elec. Engrs.*, p. 924

[9]"An Experimental Study of the Fahy Permeameter" by Chas. W. Burrows and R. L. Sanford. *Bureau of Standards. Scientific Paper. No.* 306, p. 286. August 27, 1917.

[10]"A Direct Recording Method of Measuring Magnetic Flux Distribution" by F. S. Dellenbaugh Jr., Journal A. I. E. E., p. 583, June 1920.

[11]Ewing, p. 158.

[12]Ewing, p. 362.

[13]"Picout Permeameter" by A. Campbell; *Electrician*, Vol. LVIII, p. 123, (1906); "Electrical Measurements and Practice" by Farmer, p. 330; *Standard Handbook for Electrical Engineers*, p. 189.

[14]"The Effect of Displaced Magnetic Pulsations on the Hysteresis Loss of Sheet Steel" by L. W. Chubb and Thomas Spooner, *Proceedings of A. I. E. E.*, Vol. XXXIV, 1915.

[15]"Rapid Testing of Magnetic Materials" by Thomas Spooner. *Electrical World*, Vol. LXXIV, p. 4, July, 5, 1919.

[16]"The Determination of the Magnetic Induction in Straight Bars" by C. W. Burrows, *Bulletin Bureau of Standards*, Vol. VI, p. 31 (1909). Also *Bureau of Standards Circular* No. 17, Magnetic Testing (1916).

[17]For standard methods of determining normal induction and hysteresis data, see *A. S. T. M. Standards* for 1918, p. 271.

[18]*Standard Handbook of Electrical Engrs.*, p. 186.

(To be continued)

Voltage Transformers

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VOLTAGE transformers are used to step the voltage of primary circuits down to values suitable for direct connection to instruments. They are used when the line voltage is high enough that connecting instruments directly to the circuit would be dangerous to the operator, or would make the design of the instruments impracticable. Essentially they are constant voltage transformers, designed for close regulation and most of the following relates to the question of voltage ratio, and to the time phase relation of the primary impressed and the secondary delivered voltages, under various conditions of load.

VOLTAGE AND CURRENT RELATIONS

In Fig. 1, OE_p is the voltage impressed on the primary winding of the transformer and OE_1 is that part of the primary impressed voltage which balances the counter e.m.f. due to the flux in the magnetic circuit. The difference in time phase relation and magnitude between these two voltages is the voltage drop in the primary winding, due to the primary current. In time phase opposition to OE_1 is the induced voltage OE_2 in the secondary winding. The voltage OE_s is the secondary terminal voltage and the difference between OE_2 and OE_s is due to the voltage drop in the secondary winding caused by the load current OI_s. The secondary load current OI_s lags behind the secondary terminal voltage OE_s by an angle θ, whose value depends on the impedance of the load. The impedance drop in the secondary winding of I_sZ_s is made up of two components, the ohmic element I_sR_s in phase with the current OI_s and the reactive element I_sX_s at right angles to this current. The primary current OI_p is made up of two components; the part OI_1, whose ampere turns balance the ampere turns in the secondary winding, due to the load current OI_s, and the exciting current OI_E. In turn the exciting current OI_E is made up of two parts; OI_m and OI_i. The current OI_m, at right angles to OE_1 and in phase with the flux in the magnetic circuit, is the part which magnetizes the iron. The part OI_i is in phase with OE_1 and is the current which supplies the iron loss in the magnetic circuit. The impedance drop I_1Z_p in the primary winding due to the primary load current is made up of two component; the part I_1R_p which is in phase with primary load current OI_p and the part I_1X_p which is at right angles to this current. The impedance drop I_EZ_p through the primary winding due to the exciting current, is made up of two parts I_ER_p which is in phase with OI_E and I_EX_p which is at right angles to this current.

From Fig. 1 it is apparent that the calculation of the voltage ratio of a transformer, taking into account the drop in the primary winding due to the exciting current, as well as the drop in both primary and secondary windings due to the load currents, is a matter of some complication. It is also evident that the voltages OE_p and OE_s are not in exact opposition and that the calculation of the angle by which they lack being in opposition, or the phase angle of the transformer, also is a problem of some difficulty.

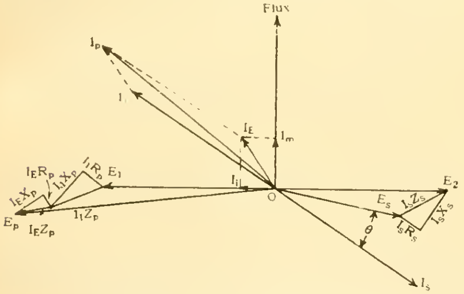


FIG. 1—VECTOR RELATIONS OF IMPRESSED AND DELIVERED VOLTAGES AND OF PRIMARY AND SECONDARY CURRENTS.
Drawn for a one to one ratio of turns

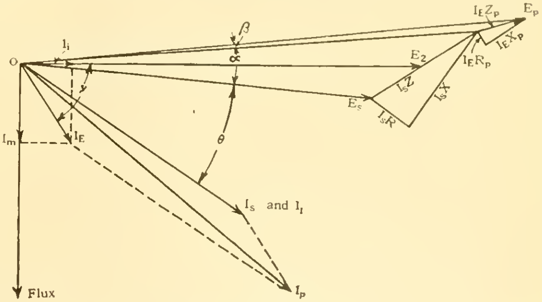


FIG. 2—VECTORS REPRESENTING THE PRIMARY VOLTAGES AND CURRENTS REVERSED
The two impedance triangles due to the load currents are combined into one.

VOLTAGE RATIO

The regulation of power and distributing transformers as ordinarily expressed is the drop in secondary voltage from no load to full load expressed as a percentage of the full-load voltage*. By definition, therefore, the regulation of such transformers is not concerned with the drop in the primary winding due to the exciting current, as this drop also occurs at no

*This article should be read as a continuation of the author's series on "The Essentials of Transformer Practice" which appeared in the JOURNAL from July 1917 to July 1919. Expressions for calculating the regulation of power transformers were developed in Part VI in the JOURNAL for Jan. 1918, p. 10.

load. For a voltage transformer, where the secondary voltage is used for metering power, it is necessary to know the ratio of the primary to the secondary voltage, under the given conditions of load, rather than the regulation. In determining this ratio it is necessary to take into account the voltage drop due to the exciting current.

In developing an expression for the ratio, it will be convenient to redraw the vector diagram in Fig. 1, reversing the time phase relation of the quantities for the primary side, as shown in Fig. 2. Since the total impedance voltage drop through the transformer windings due to the load current cannot be separated into the parts lost in the primary and secondary coils, the two impedance triangles can be combined into one, as shown in Fig. 2. Redraw part of Fig. 2 as shown in Fig. 3, and determine first the voltage ratio due to the impedance drops in the windings due to the load currents. By definition, if r is the ratio of the primary to the secondary turns.

$$\textit{Voltage ratio} = \frac{E_p}{E_s} = r\,\frac{(E_s + AF)}{E_s} = r\left(1 + \frac{AF}{E_s}\right)$$

but in Part VI p. 13 it has been shown that

$$AF = IR\cos\theta \pm IX\sin\theta + \frac{(IX\cos\theta \mp IR\sin\theta)^2}{2E_s}$$

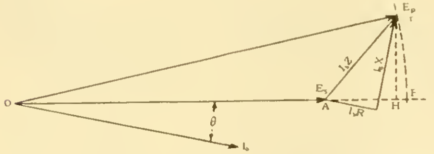


FIG. 3—IMPEDANCE TRIANGLES USED FOR DERIVING THE EXPRESSION FOR THE VOLTAGE RATIO

Therefore,—

$$\textit{Voltage ratio} = r\left[1 + \frac{I_s\,(R\cos\theta \pm X\sin\theta)}{E_s} + \frac{I_s^2\,(X\cos\theta \mp R\sin\theta)^2}{2E_s^2}\right] \qquad (1)$$

Where R and X are the equivalent resistance and reactance of the transformer winding referred to the secondary side. If the equivalent resistance and reactance are expressed in terms of the primary winding, equation (1) becomes,—

$$\textit{Voltage ratio} = r\left[1 + \frac{I_p\,(R\cos\theta \pm X\sin\theta)}{r\,E_s} + \frac{I_p^2\,(X\cos\theta \mp R\sin\theta)^2}{2\,r^2\,E_s^2}\right] \qquad (2)$$

The signs + and — are used for a lagging load current and the signs — and + are used when the load current is leading.

When taking into account the exciting current, another impedance triangle must be considered, as shown in Figs. 2 and 3. As the impedance triangle due to the exciting current is fixed in magnitude and phase position, it will add a fixed quantity to AF, which by the method used in part VI, is,—

$$I_E\left(\frac{R_p\cos\gamma + X_p\sin\gamma}{rE_s}\right)$$

Adding this to equation (1) gives,—

$$\textit{Voltage ratio} = r\left[1 + \frac{I_s\,(R\cos\theta \pm X\sin\theta)}{E_s} + \frac{I_s^2\,(X\cos\theta \mp R\sin\theta)^2}{2E_s^2} + \frac{I_E\,(R_p\cos\gamma + X_p\sin\gamma)}{rE_s}\right] \qquad (3)$$

Since the squared term of this expression is usually negligible, for ordinary work it may be neglected and equation (3) becomes,—

$$\textit{Voltage ratio (approximately)} = r\left[1 + \frac{I_s\,(R\cos\theta \pm X\sin\theta)}{E_s} + \frac{I_E\,(R_p\cos\gamma + X_p\sin\gamma)}{rE_s}\right] \qquad (4)$$

Where γ is the angle between the secondary induced voltage OE_2 and the reversed exciting current OI_E. While the equivalent reactance can be calculated from the constants of the transformer, or determined by test, it is not possible to measure directly the value of X_p. It will be sufficiently accurate for the present purpose, to assume that,—

$$\frac{X_p}{X} = \frac{R_p}{R} \text{ or}$$

$$X_p = \frac{R_p}{R}X \qquad (5)$$

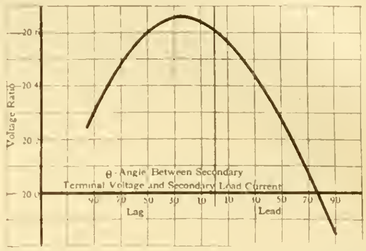


FIG. 4—VARIATION OF RATIO OF A VOLTAGE TRANSFORMER

With angle of secondary load current from secondary terminal voltage, at full load of 200 volt-amperes. Constants of the transformer are shown in Example No. 1.

Example 1 :—If a 200 volt-ampere, 60 cycle voltage transformer has the following constants at 50 degrees C, what is the voltage ratio with a load of 200 volt amperes at 80 percent power-factor?

Voltage ratio	=2300 to 115	R_p=380 ohms
Iron Loss	=20 watts	R_s=0.85 ohms
Volt Amperes at no load	=80	Z=1.95 ohms (referred to secondary)
r	=20	X=0.75 ohm referred to secondary)

The equivalent resistance referred to the secondary winding is, by equation (4) Part II,—

$$R = 0.85 + \frac{380}{20^2} = 0.85 + 0.95 = 1.8 \text{ ohms}$$

The reactance of the primary winding from equation (5), is,—

$$X_p = \frac{380 \times 0.75}{1.8} = 158 \text{ ohms}$$

$$I_s = \frac{200}{115} = 1.738 \text{ amperes} \qquad I_E = \frac{80}{2300} = 0.0348 \text{ amperes}$$

$$\cos\gamma = \frac{20}{80} = 0.25 \qquad \gamma = 75^\circ\,29' \qquad \sin 75^\circ\,29' = 0.968$$

Then from equation (3),—

$$\textit{Voltage ratio} = 20\left[1 + \frac{1.738\,(1.8\times0.8+0.75\times0.6)}{115} + \frac{1.738^2\,(0.75\times0.8-1.8\times0.6)^2}{2\times115^2} + \frac{0.0348\,(380\times0.25+158\times0.968)}{20\times115}\right]$$

$$= 20\,[1+0.0286+0.0000263+0.00375] = 20\times1.03238 = 20.647$$

In example (1) the terms 0.0286 and 0.0000263

are due to the drops through the impedance of the windings caused by the load current, and it is apparent that the quantity 0.0000263 due to the squared term is negligible. The term 0.00375 is due to the impedance drop through the primary winding caused by the exciting current and in this case is about one-eighth of the value of the term due to the load current in both windings.

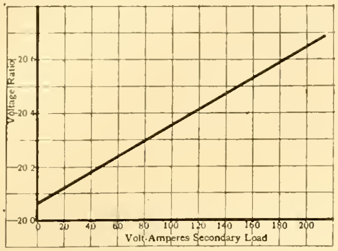


FIG. 5—VOLTAGE RATIO CURVE

Secondary load having 80 percent power-factor. The transformer characteristics are given in Examples 1, 3 and 4.

Example 2:—If a 200 volt ampere, 60 cycle voltage transformer has the following constants at 50 degrees C. what is its voltage ratio with a load of 200 volt amperes at 80 percent power-factor?

Voltage ratio	=115000 to 115	R_p=40 000 ohms
Iron Loss	=330 watts	R_s=0.1 ohms
Volt amperes at no load	=700	Z=0.161 ohms
r	=1000	X=0.079 ohms

$$R = 0.1 + \frac{40\ 000}{1000^2} = 0.1 + 0.40 = 0.5 \text{ ohms}$$

$$X_p = \frac{40\ 000 \times 0.079}{0.5} = 6320 \text{ ohms}$$

$$I_s = \frac{200}{115} = 1.738 \text{ amperes} \qquad I_E = \frac{700}{115\ 000} = 0.00609$$

$$\cos\gamma = \frac{330}{700} = 0.472 \qquad \gamma = 61^\circ\ 10'$$

$$\sin 61^\circ\ 10' = 0.881$$

Then from equation (4),—

$$\text{Voltage ratio (approximately)} = 1000 \left[1 + \frac{1.738\ (0.5 \times 0.8 + 0.079 \times 0.6)}{115} + \frac{0.00609\ (40\ 000 \times 0.472 + 6320 \times 0.881)}{1000 \times 115}\right]$$

$$= 1000\left[1 + 0.00677 + 0.001294\right] = 1000 \times 1.00806 = 1008.06$$

In this example the drop in the windings due to the load current is about five and one-half times the voltage drop in the primary winding due to the exciting current.

Example 3:—Plot the voltage ratio curve of the transformer in Example 1 for a full load of 200 volt amperes, at power-factors of 90 degrees lagging to 90 degrees leading. This curve is shown in Fig. 4.

VOLTAGE RATIO AT DIFFERENT LOADS

For practical use it is customary to plot the voltage ratio curve between the ratio as ordinates and volt amperes secondary load as abscissae. The reason for this is that one set of measuring instruments will give an entirely different load than another group, and therefore the ratio should be known for various loads. It is evident that as the secondary voltage decreases, because of the drop through the transformer windings, the voltage ratio will increase. The ratio curve will therefore take the form shown in Fig. 5 and a different curve is required for each power-factor of the load. An examination of equation (4) will also indicate that a voltage ratio curve, with changing volt ampere secondary load at a given power-factor, will be a straight line. The voltage drop in the primary winding due to the exciting current is a constant both in phase relation and magnitude. For a given power-factor of secondary load the drops in the primary and secondary windings due to the load currents are fixed in phase relation and their value is directly proportional to the secondary load current. The total drop in voltage is therefore the vector sum of the fixed voltage drop in the primary, and the drops in the two windings whose values are directly proportional to the load current. Such conditions will evidently result in the voltage ratio curve being a straight line.

Example 4:—Plot the voltage ratio curve for an 80 percent power-factor load, of the transformer covered by examples 1 and 3. The values for this curve are calculated by the use of equation (4) and the curve is shown in Fig. 5.

COMPENSATION FOR VOLTAGE RATIO ERROR

The voltage ratio curve shown in Fig. 5 does not give the correct voltage ratio at any load. The reason for the ratio being incorrect at zero load, is the drop in the primary winding due to the exciting current. In practical work, in order to avoid as far as possible the use of correction factors, the transformer may be compensated to give the correct ratio of a given secondary load. Knowing the characteristics of the magnetic circuit and the windings, the voltage ratio may be calculated for a given secondary load, and turns added to the secondary winding to compensate for the error in ratio. For loads other than the one for which the transformer is compensated, the ratio will still be incorrect. For volt ampere loads less than the one for which compensation is made the ratio will be low, and for larger loads the ratio will be high, as is shown in Fig. 6.

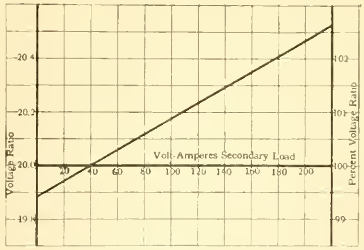


FIG. 6—VOLTAGE AND PERCENT VOLTAGE RATIO CURVE

Compensated for 40 volt-ampere load at 80 percent power-factor. The transformer characteristics are given in Examples 1, 3, 4, 5 and 6.

Example 5:—For the transformer whose voltage ratio curve is shown in Fig. 5, draw the ratio curve when the transformer is compensated for the ratio error at one-fifth normal rated secondary load and at 80 percent power-factor.

At one-fifth rated secondary load or 40 volt amperes, the ratio of this transformer, from Fig. 5, is approximately 20.19. In order to bring the ratio to 20 at 40 volt ampere load, the secondary voltage must be raised to $230 \times \frac{20.19}{20} = 232.185$ volts,

or in other words the secondary turns of the transformer must be increased 0.95 percent. The voltage ratio curve for this condition is shown in Fig. 6.

PERCENT VOLTAGE RATIO AT DIFFERENT LOADS

In order that the voltage ratio may be used as the direct correction factor to apply to a power reading obtained by the use of a voltage transformer, equation (4) may be arranged to give the percentage ratio by dividing through by the marked voltage ratio of the transformer.

Percent voltage ratio (approx.)

$$= \frac{100r}{\text{marked ratio}}\left[1 + \frac{I_s\,(R\cos\theta \pm X\sin\theta)}{E_s} + \frac{I_E\,(R_p\cos\gamma + X_p\sin\gamma)}{rE_s}\right] \quad (6)$$

Example 6:—Draw the percent voltage ratio curve for the transformer whose voltage ratio curve is shown in Fig. 6.

The ordinates for this curve are obtained by multiplying the ordinates of Fig. 6 by 100 and dividing by 20. The new scale of ordinates is shown at the right in Fig. 6..

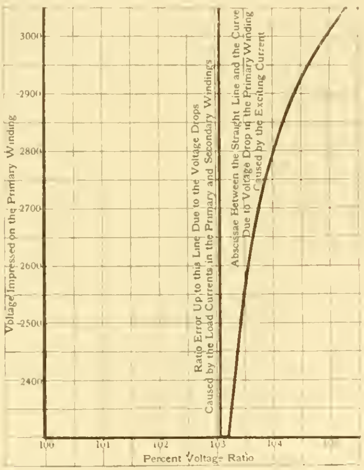


FIG. 7—EFFECT OF CHANGE IN OPERATING VOLTAGE ON THE PERCENT VOLTAGE RATIO

With constant secondary load of 200 volt-amperes at 80 percent power-factor. The transformer is the same as covered by Examples 1, 3, 4 and 5.

When using the percentage ratio curve of the transformer employed in making a power measurement, in order to eliminate the error due to its voltage ratio, the power reading should be multiplied by the percentage ratio divided by 100, or,

$$\textit{True power} = \frac{\textit{percent ratio}}{100} \times \textit{power reading} \quad (7)$$

Example 7:—If the transformer whose percent ratio curve is shown in Fig. 6 is used in making a power measurement, and the load on the transformer is 90 volt-amperes with an 80 percent power-factor load, what is the true value of the power when its apparent value is 90 kw?

From Fig. 6 the percent ratio at 90 volt amperes and 80 percent power-factor is 100.7. From equation (7),—

$$\textit{True power} = \frac{100.7}{100} \times 90 = 90.6\ \textit{kw}$$

EFFECT OF CHANGE IN OPERATING VOLTAGE

In investigating the effect of a change in the primary operating voltage on the characteristics of a voltage transformer, it will be assumed that the secondary load is constant in magnitude and power-factor. The change in percent voltage ratio will, therefore, be that due to the increase in the exciting current, as the primary impressed voltage grows larger.

TABLE I—EFFECT OF INCREASED PRIMARY VOLTAGE

Impressed Voltage	Watts Iron Loss	Volt Amperes at No Load
2300	20	80
2400	21.5	100
2500	23.5	130
2600	26	170
2700	28	200
2800	30.5	300
2900	33.5	420
3000	36.5	600

Example 8:—Draw a curve between the percent voltage ratio as abscisscae and the primary impressed voltage as ordinates for the voltage transformer covered by examples 1,3,4 and 5 when the secondary load is constant at 200 volt amperes and 80 percent power-factor. Assume also that the iron loss and volt-amperes at no load, of the transformer are given in Table I for the various impressed primary voltages.

The percent voltage ratio curve is shown in Fig. 7 as plotted by the use of equation (4).

The abscissae up to the vertical straight line in Fig.

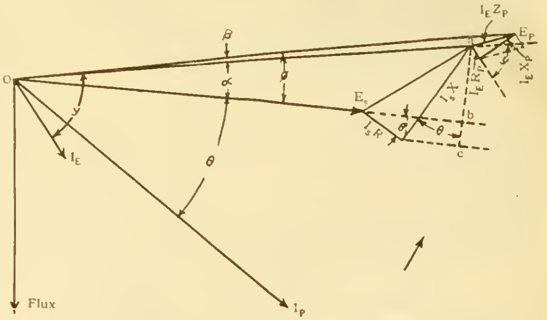


FIG. 8—IMPEDANCE TRIANGLES USED FOR DERIVING THE EXPRESSION FOR THE PHASE ANGLE

7 represents the constant voltage drop in the transformer due to the load current and the abscissae between this straight line and the curve represent voltage drops in the primary winding due to the exciting current. The value of the component caused by the exciting current for the maximum impressed voltage is approximately two-thirds of the constant value caused by the load currents. For the transformer covered by Example 2, the voltage drop resulting from the exciting current is relatively large compared to that resulting from the load currents. Therefore, for that transform- the voltage ratio errors caused by the exciting current at primary voltages above normal, are relatively large compared to those for the transformer covered by example No. 1.

PHASE ANGLE

The phase angle of a voltage transformer, as is

shown in Fig. 2, is the angle between the reversed primary impressed voltage OE_p and the secondary delivered voltage OE_s. It is customary to think of the phase angle as lagging, when the secondary delivered voltage lags behind the reversed primary impressed voltage, and leading when the secondary is ahead of the reversed primary voltage. The phase angle is the

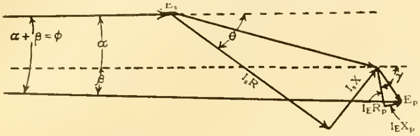


FIG. 9—IMPEDANCE TRIANGLES DRAWN TO SCALE

For values given in Example 1, which are comparable with the values usually found in practice.

sum of the angles α and β shown in Fig. 2 taking into account that the angle β must be added to or subtracted from α depending upon the particular conditions involved. Therefore,

$$\textit{Phase angle} = \alpha + \beta = \phi$$

The first step in deriving an expression for the phase angle is to determine the angle α. To make the development more clear, a part of Fig. 2 may be redrawn as shown in Fig. 8. Since the sine of a small angle is approximately equal to the angle expressed in radians,—

$$\alpha = \frac{ab}{E_s} \text{ (approximately) but}$$

$$ab = ac \pm bc$$

$$= I_s (X \cos\theta \pm R \sin\theta)$$

therefore,

$$\alpha = \frac{I_s (X \cos\theta \pm R \sin\theta)}{E_s} \qquad \ldots(8)$$

The plus sign is to be used for secondary currents

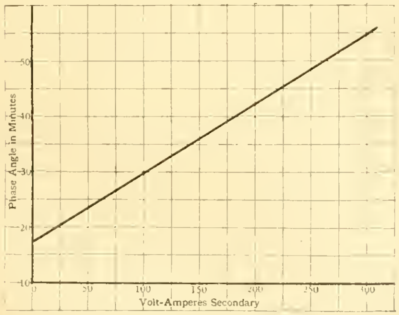


FIG. 10—PHASE ANGLE OF THE TRANSFORMER IN EXAMPLE 1

At various values of the volt-ampere secondary load, which has a power-factor of 80 percent. In this case the phase angle is leading.

of leading power-factor, and the minus sign for lagging power factor currents. Similarly,—

$$\beta = \frac{I_E (X_p \cos\gamma - R_p \sin\gamma)}{rE_s}$$

A minus sign is always to be used between these two terms, because the conditions are similar to a lagging power-factor load, since the exciting current always lags behind the primary impressed voltage.

In Fig. 8 the assumption regarding the angle γ is not quite correct, since the true value of γ, as is shown in Fig. 2, is the angle between the voltage OE_2 and the current OI_E. The phase angle therefore is,—

$$\phi = \alpha + \beta \text{ (radians)} = \frac{I_s (X \cos\theta \pm R \sin\theta)}{E_s} + \frac{I_E (X_p \cos\gamma - R_p \sin\gamma)}{rE_r} \qquad \ldots(9)$$

A consideration of equation (9) will indicate that when the phase angle is positive in sign, OE_s is lagging in phase relation behind OE_p, and when the phase angle is negative in sign that OE_s leads in phase relation the voltage OE_p. As a matter of fact the phase angle is usually negative with lagging loads. In Figs. 1, 2, 3, and 8 the impedance triangles have been greatly exaggerated, as they would not be legible if drawn to scale on a complete vector diagram. In Fig. 9 these triangles have been separated from the rest of the vectors and drawn to scale, from the constants given in Example 1, with a load of 200 volt amperes at an 80 percent lagging power-factor. Fig. 9 shows that the phase angle θ will usually be negative with a lagging load, on account of the great preponderance of resistance over reactance in the usual commercial

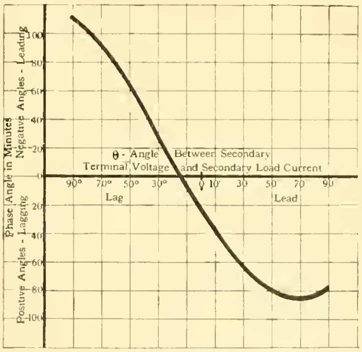


FIG. 11—VARIATION OF THE PHASE ANGLE WITH THE ANGLE OF SECONDARY LOAD CURRENT FROM SECONDARY TERMINAL VOLTAGE

At full load of 200 volt-amperes. Constants of the transformer are given in Example 1.

transformer, although this angle must be positive with a load of unity power-factor.

Equation (9) may be written as follows to express the phase angle in minutes,—

$$\textit{Phase angle (min.)} = 3438 \left[\frac{I_s (X \cos\theta \pm R \sin\theta)}{E_s} + \frac{I_E (X_p \cos\gamma - R_p \sin\gamma)}{rE_s}\right] \qquad \ldots(10)$$

Example 9:—What is the phase angle at 50 degrees C of the voltage transformer whose characteristics are shown in Example 1, with a load of 200 volt amperes at an 80 percent lagging power-factor?

From equation (10),—

$$\textit{Phase angle} = 3438 \left[\frac{1.738\ (0.75 \times 0.8 - 1.8 \times 0.6)}{115} + \frac{0.0348\ (158 \times 0.25 - 380 \times 0.968)}{20 \times 115}\right]$$

$$= 3438\ (-0.00725 - 0.00499) = 3438\ (-0.01224) = -42 \textit{ min.}$$

The minus sign of the phase angle indicates that the secondary voltage is leading the reversed primary voltage, as shown in Fig. 9. The relative values of the two terms 0.00725 and 0.00499 indicate the relative amounts which the voltage drops due to the load currents and the exciting current, respectively contribute to the phase angle of the transformer under the particular conditions of the example.

Example 10:—What is the phase angle at 50 degrees C, of the transformer whose characteristics are shown in example 2, with a load of 200 volt amperes at an 80 percent lagging power-factor?

From equation 10,—

$$Phase\ angle = 3438\left[\frac{1.738\ (0.079 \times 0.8 - 0.5 \times 0.6)}{115} + \frac{0.00609\ (6320 \times 0.472 - 40\,000 \times 0.881)}{1000 \times 115}\right]$$

$$= 3438\ (-0.00357 - 0.00171) = 3438\ (-0.00528) = -18.15\ min.$$

While Example 9 gives the phase angle of the transformer for a particular condition of secondary load, this single value would be of very little practical use. The secondary load conditions in another application of the transformer might be entirely different, both as regards magnitude and power-factor. It is therefore, customary to plot phase angle curves for voltage transformers, showing the phase angle for all values of the secondary volt ampere load. It is of course necessary to plot a different curve for each power-factor of secondary load.

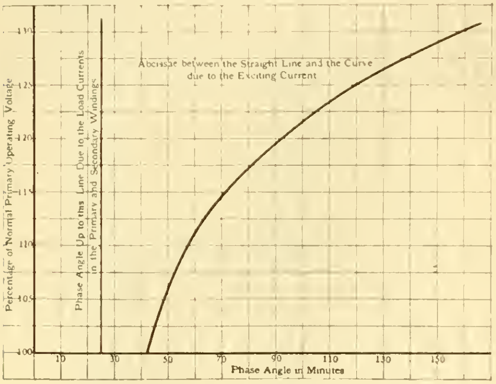


FIG. 12—EFFECT OF CHANGE IN OPERATING VOLTAGE ON THE PHASE ANGLE

With constant secondary load of 200 volt-amperes at 80 percent power-factor. The transformer is the same as covered by Examples 1 and 9.

Example 11:—Plot the phase angle curve of the transformer in Example 1, up to 300 volt ampere load.

This curve is shown in Fig. 10.

Example 12:—Plot the phase angle curve for the transformer in Example 1, for a full load of 200 volt amperes, at load power-factors corresponding to 90 degrees lagging to 90 degrees leading.

This curve is shown in Fig. 11.

EFFECT OF CHANGE IN OPERATING VOLTAGE ON PHASE ANGLE

In investigating the effect of increasing the operating voltage on the voltage ratio, the secondary load was maintained constant so that the change in ratio was due to the increase in the exciting current of the transformer at their higher voltages. For this same reason the secondary load will be considered as constant, when analyzing the effect on the phase angle of increasing operating voltage.

Example 13:—Draw a curve between the phase angle as abscissae and the primary impressed voltage as ordinates, of the voltage transformer in Example 1, when the secondary load is constant at 200 volt amperes and 80 percent power-factor. Assume, also, that the iron loss and volt amperes at no load for the various impressed voltages are the same as those given in Table I.

This curve is shown in Fig. 12. The abscissae up to the vertical straight line represent the constant phase angle due to the load currents in the primary and secondary windings. The abscissae between this straight line and the curve represent phase angles due to the exciting current for each value of primary winding. The phase angle due to the exciting current for each value of primary impressed voltage is constant, while the angle due to the load current is dependent on the power-factor of the secondary load. For a power-factor of secondary load other than 80 percent, as used in Fig. 12, the relative values of the two factors contributing to the total phase angle would be entirely different. From a comparison of Figs. 8 and 12, it is apparent that the exciting current is relatively a greater factor in causing the phase angle than it is in contributing to the ratio error.

CORRECTION FOR RATIO AND PHASE ANGLE ERRORS

As indicated in equation (7) the percent ratio divided by 100 is the direct correction factor to apply to a power reading obtained by the use of a voltage transformer, to correct for the ratio error.

The displacement of the secondary terminal voltage from the reversed primary voltage need not be considered when the transformer is used with instruments which depend on the voltage only. When the transformer is used in metering power, the effect of the phase angle must be taken into account, as the power reading will vary slightly with the phase angle of the transformer. From Fig. 13 it is evident,—

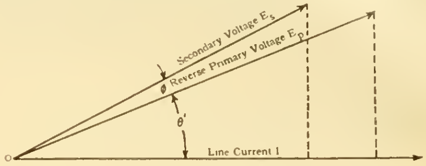


FIG. 13 VECTOR RELATION BETWEEN THE LINE CURRENT AND THE REVERSED PRIMARY AND THE SECONDARY VOLTAGES

The secondary voltage is shown as leading the reversed primary voltage.

$$True\ power = IE_p\cos\theta'$$

$$Power\ reading = IE_s \times marked\ ratio \times \cos(\theta' \pm \phi)$$

$$True\ power = \frac{E_p}{E_s} \times \frac{1}{marked\ ratio} \times \frac{\cos\theta'}{\cos(\theta' \pm \phi)} \times power\ reading$$

$$= \frac{true\ ratio}{marked\ ratio} \times \frac{\cos\theta'}{\cos(\theta' \pm \phi)} \times power\ reading$$

$$= \frac{percent\ ratio}{100} \times \frac{\cos\theta'}{\cos(\theta' \pm \phi)} \times power\ reading$$

The plus sign is to be used when the phase angle is leading and the minus sign when it is lagging.

Example 14:—What is the true power when a power reading of 75 kw is secured by the use of a voltage transformer whose percentage ratio is 101.35 and whose leading phase angle is 50 minutes, and the power-factor of the line current is 80 percent.

From equation (11),—

$$True\ power = \frac{101.35}{100} \times \frac{0.8}{\cos(36^\circ52' + 50')} \times 75 = \frac{101.35}{100} \times \frac{0.8}{0.7912} = 76.9\ kw.$$

OTHER FACTORS EFFECTING RATIO AND PHASE ANGLE

All influences tending to increase the iron loss and exciting current of a voltage transformer will increase both the ratio and phase angle errors. The most im-

portant of these factors, aside from operating at voltages above normal, are:—

1—Iron ageing.
2—Variations of wave of e. m. f.
3—Operation at reduced frequency.

When non-aging silicon steel is used in the construction of the voltage transformer, the matter of the influence of the iron ageing on the ratio and phase angle may be ignored, for the reason that a small increase in the iron loss and exciting current would change the ratio and phase angle a very small amount. For the same reason the variation of the wave form of e.m.f. met with in ordinary commercial work does not increase the iron loss and exciting current enough to increase the ratio or phase angle error seriously.

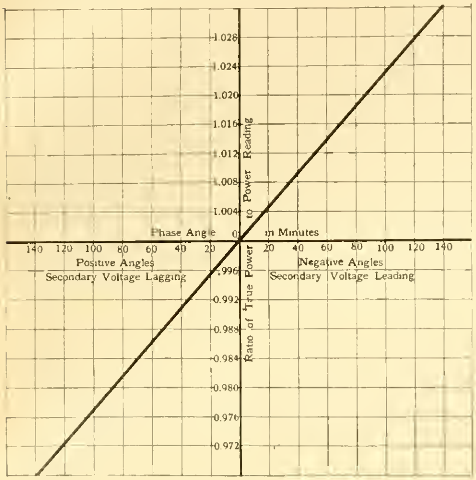


FIG. 14—EFFECT ON THE POWER READING OF VARIOUS VALUES OF THE TRANSFORMER PHASE ANGLE

On the assumption that the power-factor of the line is 80 per cent.

However, operating a transformer at a reduced frequency may considerably increase the iron loss and exciting current and thus increase the ratio and phase angle error. For example, operating a 60 cycle transformer on a 50 cycle circuit would increase the induction in the magnetic circuit twenty percent. This would cause a decided increase in the ratio and phase angle errors, which would be comparable to the increased error caused by an increase of 20 percent in the operating voltage, as shown in Fig. 12. Operation at 50 cycles, of course, would be permissible if the transformer characteristics at 60 cycles were sufficiently good that increased iron loss and exciting current at 50 cycles would not be objectionable.

POLARITY

Fundamentally the term polarity has the same significance when applied to a distribution or power transformer. The matter of polarity is important as applied to distribution or power transformers, when such units are to be paralleled. A knowledge of the polarity permits the placing the proper leads together to establish the proper parallel connection. A knowledge of the polarity of a voltage transformer establishes the phase of the secondary voltage as related to the phase of the voltage impressed on the primary winding, and also the relative instantaneous direction of the currents in the primary and secondary leads. The polarity of voltage transformers is usually indicated by marks on one primary and on one secondary lead. The marks are made so that the instantaneous direction of the currents are the same in the two marked leads. For example, if the current flows toward the transformer in the marked primary lead, it will flow away from the transformer in the marked secondary lead.

THE ELECTRIC JOURNAL

OPERATING DATA FOR CONVERTING SUBSTATIONS

JULY 1921

Installation of Switching Equipment for Synchronous Converter Substations

Preparatory to installing switching equipment for a synchronous converter substation, a general arrangement for locating the equipment should be carefully laid out in accordance with a diagram, so that each piece will go into the most suitable position, without requiring any rearrangement of apparatus during or after installation. If the substation is a new building, the design of the building should be made to accommodate the synchronous converters, transformers and switching equipment in the best possible manner. If an old building is used, considerable remodeling may be needed to obtain the best arrangement.

When possible, the high-tension equipment should be segregated from the low-tension equipment. The high-tension leads should come in at one end of the building, pass through the high-tension switching equipment into the transformers. The low-tension wiring should be made to the synchronous converter through the starting panel, to the direct-current switchboard and thence to the low-tension feeders, these feeders leaving the building at the opposite end from the incoming line. This arrangement permits of the total isolation of all high-tension equipment, either within a suitable room or behind a separate protecting guide rail or barrier; and of the shortest possible runs for the cable and connections. Fig. 1 shows a substation designed as outlined above.

The high-tension lightning arresters are usually mounted outdoors, in order to reduce the required building space. The low-voltage lightning arresters, on account of their construction, must necessarily be kept inside. Where outdoor space is at a premium, the lightning arresters can be placed advantageously on the roof of the substation building, as shown on Fig. 2. The choke coils can be located outdoors or indoors as desired.

The high-tension disconnecting switches, oil circuit breakers, instrument transformers, etc. should be mounted as close to the wall entrance bushing as feasible. Due allowances, of course, must be made for the inspection, repairs and removal of any apparatus without disturbing the rest of the equipment. This apparatus should be so grouped that all the connections run in as nearly a straight line as possible.

The alternating-current control board should be located in a central and convenient position. The circuit breakers are usually operated therefrom by means of remote mechanical or electrical control. The starting panels should be located in a direct line between the synchronous converter and its own transformer or transformer bank. This will reduce the amount of cable connections between transformer and converter to their shortest possible length, and save considerable in cost of installation.

The panels controlling the direct-current end of the converter and the direct-current feeders should be grouped, and the whole switchboard located in the position central to the total number of synchronous converters, thus making the cable connections more or less equal from each machine. This location of the direct-current switchboard will usually be such as to give a general view of the substation, especially if the station is small.

The synchronous converter starting panels should be located so that they do not interfere with the accessibility of the converter for inspection, repairs and its possible removal.

The equalizer switch may be mounted on the starting panel. This location will shorten the equalizer cables. In railway substations the negative switch is sometimes mounted in addition to the equalizer switch, on the starting panel; or the two switches may be mounted on an equalizer pedestal, which is located near the converter.

The switching equipment and switchboard panels should be mounted, if possible, so that very little of the machine vibration will be transmitted to them. This applies particularly to the switchboard panels on which instruments and carbon circuit breakers are mounted. These instruments must be as free as possible from any vibration if accuracy and good operation conditions are to be maintained.

The actual time required for the construction work and erection of the equipment can be considerably reduced if all mounting details are located before the arrival of apparatus. The mounting bolts for current transformers, disconnecting switches, pipe mounting brackets, etc. should be in the wall and well set before the apparatus is put thereon. The setting of these bolts requires time. The channel iron base or other means for supporting the panels, should be put in place so that the switchboard may be erected directly upon its arrival. The board should be well supported from the rear by wall or floor braces or by some other means that is deemed safe and practical. The complete bracing should be done at the time the board is erected to prevent any accident to the board due in inferior and temporary bracing.

Where circuit breakers, disconnecting switches, etc. are mounted on pipe framework, this framework should be assembled and erected complete before any of the apparatus is mounted. The same applies to masonry cell structure if used instead of pipe structure for the equipment. Care should be exercised in erecting cell structure. Provision must be made for all necessary openings. The conduits for instruments and control wiring must all be be put in and the mounting bolts for bus-bar supports, disconnecting switches and instrument transformers must be in place before the concrete or brick work is completed. It is very important that this work be complete with nothing omitted when the cell structure is finished, or considerable time and expense will be involved in making additions. The separate pieces of apparatus should be mounted before any of the wiring is installed and the connections in the interior of the substation made, including ground connections, before the high-tension switches are connected to the supply lines.

Disconnecting switches should be located at a height which is beyond the possibility of accidental contact, yet within reasonable reach for operating purposes. They should also be located in such a way that gravity will tend to open rather than close them. Care must be observed that they hang plumb, and that the blades in the open position will not interfere with any of the wiring. Extreme care must be observed to see that switches are properly lined up, that is that the blades make full and proper contact both at the hinge jaw and at the break jaw, and that they enter the break jaw without excessive manipulation. It is sometimes necessary to grind in the blade, using an application of vaseline mixed with pumice stone or scouring powder on blades at contact points. This grinding in process can be done very easily and quickly by opening and closing the switch blades several times. This mixture must be removed before the switch is put into actual operation. The connections to the switch must be on clean surfaces. The strap or terminal connections should be parallel to the surface of the connection block or lamination before bolting down. Care must be observed to prevent external connections to the switch applying any great amount of strain upon the switch itself. To prevent this, heavy cable and other connections to the switch should be well supported.

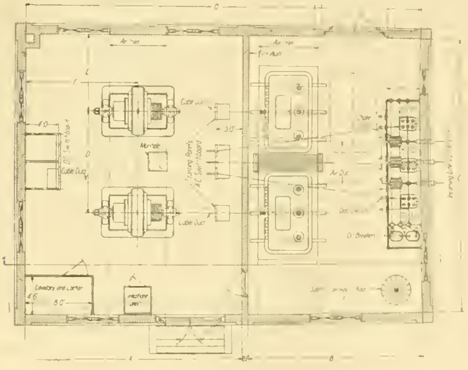


FIG. 1.

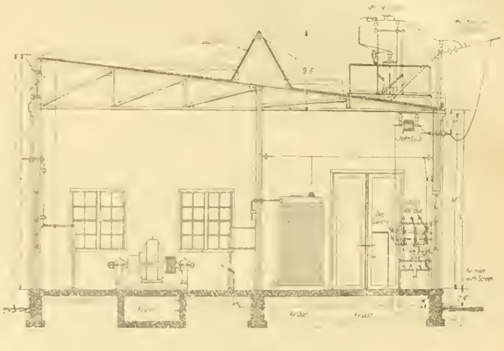


FIG. 2.

Oil circuit breakers that are mounted on masonry walls must be attached with bolts well imbedded in the wall. Where thin walls are used, such as four inch structures, it is desirable to run the mounting bolts through the wall and add plate washers under the bolt heads. Pipe frame breakers must be so supported that no undue strain comes upon any individual section of the pipe. The whole supporting structure must be very rigid and able to withstand the opening and closing of the breakers without undue vibration. Extra heavy breakers require rear pipe supports. These supports must be so adjusted that they take their proper share of the total load. The breakers must be installed in a position that permits accessibility for inspection and repair of contacts and removal of oil tanks. This location must also be such as to present no danger to the attendants or interference with the adjacent apparatus when their repair or inspection is being made. The operating mechanisms must be carefully checked and adjusted. Remote control hand operated breakers should be so arranged that the operating pipes are in tension when closing the breaker. The force for closing the breaker must not be so great as to tend to pull the bell cranks from their foundations. This is liable to happen unless careful adjustment of the travel has been made by means of the set screw on breaker frame and the correct proportioning of the connecting rods. If this set screw is too far out, it will prevent the breaker from locking in. If this occurs the operator will attempt to force the breaker closed thus pulling up the bell crank bearings. Precaution must also be taken against the set screw not being out far enough, otherwise the travel will be too far and injure the breaker contacts. The bell cranks with their operating rods should be mounted below the floor or in trenches. These trenches should be of sufficient depth that the bell cranks will not project above the floor level and be a menace to the sta-

tion attendants. The operating coil voltages of electrically operated breakers require checking against the available operating voltage of the station. The dash pots and accelerating devices for hand operated breakers must be carefully checked to see that there is no interference to good operation. The adjustment of the main brush contacts and arcing tips must be checked. It is very important that the brushes make good contact to reduce heating and trouble from arcing. This check can very easily be made by moving the breaker contacts slowing in and out and noting whether the moving contacts press well against the stationary contacts. A shiny surface indicates good contact. but the check for pressure of contact can also be made by feeling the contact when the breaker is closing and noting the force required to close it. These adjustments are all made at the factory and if the breaker is not disturbed during shipping, unpacking and setting up, a mere check is all that is necessary, with perhaps a few minor adjustments. Dirt and foreign substances such as excess paint, rust, etc. must be removed from moving contact surfaces of pins, bell cranks, etc., and oil applied. After the connections have been made to the breaker, the terminals should be insulated with tape or micarta housings of some kind.

Current transformers, potential transformers, fuses, etc. may be mounted directly upon the wall or upon suitable supporting brackets. Fuses should be accessible for replacement. The same care must be exercised in making connections to the current transformers as has been mentioned previously for the disconnecting switches.

In locating lightning arresters, the horn gaps must be in such a position that in arcing they will not flash to ground or to the line wires. The arrester proper should be protected by suitable screening or barriers.

The panels must be erected so that they are plumb and supported and braced in such a way as to keep them rigid. Circuit breakers and knife switches mounted on switchboard panels are lined up before leaving the factory. It is well, however, to check this alignment before putting the board in service as it may have been disturbed through shipment or while erecting.

Cable connections to the knife switches and circuit breakers must be supported so as to take the strain and prevent the cable from pulling out of the terminals if they should become overheated and melt the solder. This same precaution should be exercised in installing ammeter shunts. The resistance bars of the shunt are soldered to the end blocks. Therefore, if any weight is suspended from these shunts they are liable to pull apart, especially if they become heated and melt the solder.

The switchboard panels should be located a sufficient distance from the wall or other obstruction to permit of ready access to the rear for inspection or repairs. All connections to copper bus-bars or circuit breakers and knife switch studs should be cleaned before connected. This will prevent undue resistance drop and heating at these connecting points.

A. J. A. Peterson

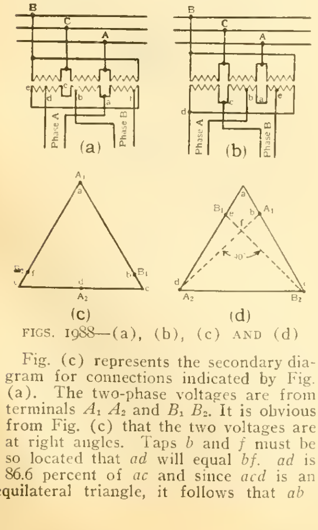
THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

1988—Two-phase to Three-phase transformer connections for two-phase to three-phase transformation are shown in Figs. (a) and (b). Will you discuss these in detail showing how to calculate the tap points and give vector diagrams and explain how these connections give a balanced two-phase voltage. Can the three-phase windings be connected in star and have the neutral grounded? Would the third harmonic be eliminated in the star connected, three-phase and the closed delta sides.

J. R. B. (Illinois)



Figs. 1988—(a), (b), (c) and (d)

Fig. (c) represents the secondary diagram for connections indicated by Fig. (a). The two-phase voltages are from terminals A_1 A_2 and B_1 B_2. It is obvious from Fig. (c) that the two voltages are at right angles. Taps *b* and *f* must be so located that *ad* will equal *bf*. *ad* is 86.6 percent of *ac* and since *acd* is an equilateral triangle, it follows that *ab* and *af* must equal 86.6 percent of *ac*, which fixes the location for the taps. Fig. (d) represents the secondary diagram for connections indicated by Fig. (b). The two-phase voltages are from A_1 A_2 and B_1 B_2. Taps *b* and *e* must be so located as to give a right angle between the two phases as indicated in Fig. (d). In order that angle *dfc* be 90 degrees angles *fdc* and *fcd* must each be 45 degrees. Angle *adc* is 60 degrees; therefore *adf* is 15 degrees and *abd* is 105 degrees.

From the law of sines:—

$$\frac{ab}{ad} = \frac{\text{Sin } 15^\circ}{\text{Sin } 105^\circ} \text{ or } ab = 0.267 \times ad$$

$$\text{Also, } \frac{bd}{ad} = \frac{\text{Sin } 60^\circ}{\text{Sin } 105^\circ} \text{ or } bd = 0.9 \times ad$$

ad is the phase voltage and is 1.11 times the two-phase voltage. The primary or three-phase side for either connection can be connected in star with or without the neutral grounded. In this respect it is the same as a star-delta three-phase connection and therefore will not contain third harmonic voltages. J. F. P.

1989—Equivalent Spacing of Transmission Lines—(a) In his article on "Electrical Characteristics of Transmission Circuits", Aug. 1919, p. 314, Mr. Nesbit states that the "equivalent spacing" in the case of three unsymmetrically spaced conductors is to be taken as the cube root of the product of the spacings. He states, further, that the line must be considered transposed to make this equivalent spacing give accurate results. I have always understood that, if the line is transposed, the equivalent spacing should be taken as the average spacing; whereas, if the line is not transposed, the cube root of the product of the spacing should be taken. Will you please inform me which is correct? (b) Two three-phase 4/0 stranded double braid, weather proof insulated feeders are strung on standard N. E. L. A. six-pin cross-arms, one circuit being on each side of the pole. The two circuits are tied together at each end. What scheme of pairing the conductors will give the minimum inductance drop, and what would be the "equivalent spacing" in this case?

E. N. D. (Cal.)

(a) The statement that the equivalent spacing in the case of three unsymmetrically spaced conductors is to be taken as the cube root of the product of the spacing is correct. The average of the spacings is only an approximation of the equivalent spacing and is not technically exact. The method of equivalent spacing is accurate only if the transmission lines are symmetrically transposed. If the lines are not symmetrically transposed, there will be unequal drop in the different wires due to the difference in mutual reactance.

(b) The arrangement of conductors on a six-pin cross-arm having one three-phase circuit on each side of the pole will give the lowest reactance. In general, to reduce the reactance of a circuit to the minimum, the conductors in parallel should be separated as far as possible. This greatest mean separation is accomplished by connecting the conductors 1 and 4, 2 and 5, and 3 and 6, in parallel, numbering from one end of the cross-arm. R. D. E.

1990—Current Rating of Switches—Why is it that switches are given a higher ampere rating for direct current than for alternating current? This question has come up in instal-

ling a triple-pole switch of the open type. Its rating is 2500 amperes, direct-current, and 2300 amperes alternating-current. E. M. (N. Y.)

Any solid conductor of electric current may be considered as being made up of a number of smaller filaments or conductors, each filament carrying a certain portion of the total current. If the conductor be straight and of uniform cross-section, and if the e. m. f. impressed across the terminals of the conductor does not vary with time, each filament will carry the same amount of current. If, however, an alternating e. m. f. be impressed across the terminals of the conductor, the current will not divide uniformly throughout the cross-section of the conductor. This is called "skin effect" and may be conveniently explained by noting that the inner filaments of the conductor are linked by more flux than the outer filaments. As a result, the counter e. m. f. induced in the inner filaments is greater than that induced in the outer filaments, and because of the lower impedance more current flows through the outer filaments. The effective resistance of the conductor is thereby increased, and this explains why, for conductors of the same size, one carrying 60 cycle current runs hotter than the one carrying direct-current of the same value. Since "skin effect" varies directly as the cross-section of a conductor, there is usually no difference in the alternating-current and direct-current ratings of switches and circuit breakers below 1200 amperes carrying capacity. However, "skin effect" also varies directly as the frequency, and for high frequencies the difference between the alternating-current and direct current ratings would extend to still smaller capacities. As a rule, however, commercial applications do not go above 60 cycles. G. G. G.

1991—Reclaiming System—Will you please furnish us with any information that you may have on the so-called "Reclaiming System" installed by large factories for washing the rags and waste used for wiping off oil, polishing surfaces or other purposes. The reclaiming system, besides furnishing the men with clean absorbent rags and waste, also reclaims the oil. T. J. M. (OHIO)

The reclaiming system consists in several steps namely; a centrifugal machine for driving off the oil, a washing machine for washing the rags and a drying oven subsequently drying them. There are several makers of this class of apparatus on the market. In this cleaning process, rags have one advantage over waste in that metal filings and turnings do not adhere to them to the same extent as they do to the waste. Neither rags nor waste should be allowed to accumulate even for a few hours, as spontaneous combustion may occur. This feature has led a number of concerns to do away with the reclaiming process where it otherwise would have been successful. C. B. A.

1992—Reconnecting Induction Motor—We have a 7.5 hp, single-phase, 133 cycle, 8 pole, 104 volt, short-circuiting commutator motor which we want to operate on a 60 cycle circuit. At present, the poles are two in series, four in parallel. Can the stator winding be reconnected for 220 volts, 60 cycles and at what speed will it run? What would cause this motor to start up and come up to speed, but as soon as the governor short-circuits the commutator, it comes to a stand still. N. J. W. (N. Y.)

We see no reason why this machine cannot be reconnected to operate on 60 cycles, 220 volts. The machine being connected in four parallels for 104 volts 133 cycles has a field strength which can be refered to as its normal field. If it is reconnected in series it operates on 416 volts, 133 cycles or on 188 volts 60 cycles with this same normal field strength. To operate on 220 volts 60 cycles would cause the motor to run with a magnetic field 17 percent stronger than normal. This is not too much increased field for standard motors, and especially when the frequency is reduced. The horse-power rating of the machine would be reduced in percent even more than the frequency, and would not be more than three hp, at most. The new synchronous speed would be 900 r.p.m. We assume that the commutator is short-circuited by centrifugal action of the governor weights. These weights must be changed and adjusted to such value as to make the short-circuiting device act near 3/4 to 5/6 of the new full-load speed. Concerning the failure of the motor to come up to speed when the short-circuiting device has acted, it would appear that the short-circuiting device fails to short-circuit the bars when the brushes have lifted. The member which short-circuits the bars may be burned out or damaged. H. S. S.

1993—Static Wires of Transmission Circuits—By referring to Fig. (a) we have a three-phase, 110 kv transmission line, *A*, *B*, and *C* being the line conductors. *X*, and *X'* are the static wires. Some claim that the static wires neutralize the induction and that it is not necessary to transpose the transmission line. Is this so? If so explain how this is brought about, also what determines the position of the static wire relative to that of the line conductors. Will the static wires help in keeping down the induction on a telephone line run on the same poles as the transmission line. In the above case the poles are 400 feet apart, and the static wires are grounded every 800 feet. R. H. N. L. (BRITISH COLUMBIA)

As the transmission line consists of three conductors equally spaced in a horizontal plane, and the ground wires are located symmetrically with respect to and in a plane above the transmission line, the ground wires form a closed circuit at the end of the 800 foot sections, at which points they are connected to ground. Under no-load conditions, there would be a voltage induced electrostatically in each ground wire. These voltages would be of different phase, and consequently cause a current to circulate in the loop formed by the ground wires. In general, the current flowing in this loop would be of such duration as to neutralize the electrostatic effects of the transmission wires. The effect on an adjacent telephone system would be to slightly reduce the induced voltage. Under load conditions, the effect of the currents in the different wires would be to induce electromagnetically a voltage in the ground wire loop, which would cause current to flow in such direction as to reduce the voltage induced by the transmission line

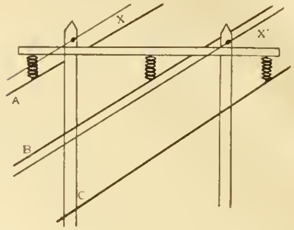
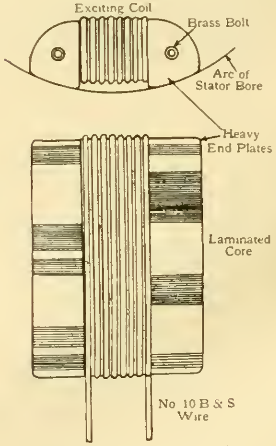


FIG. 1993 (a)

currents. The effect on adjacent telephone lines would be to reduce the amount of induced voltage slightly while the effect of the ground wire loop would be to reduce the value of voltage induced in the telephone circuits slightly, this reduction would be so small that the effect of the ground wire should not enter into the question of whether the transmission wire should be transposed or not. R. D. E.

1994—Locating Short Circuits in Stator Coils—Please give data on the winding of an electromagnet for use on a 110 volt lighting line for locating short circuits in stator windings. I have made several unsuccessful attempts using about 22 or 44 sq. inches of soft wrought iron and using 60 turns of No. 4 square magnet wire or around 60 to 75 feet of wire. Where could I get some laminated iron? G. H. G. (NEW JERSEY)

The electromagnet used in testing for short-circuits in stator coils, consists



FIGS. 1994—(a) AND (b)

essentially of built up U-shaped punchings with an exciting coil wound upon them, as shown in Fig. (a). For testing small stator coils, the magnet core having a cross-section of about six square inches will require approximately 120 turns of No. 10 B. & S. wire in the exciting coil, for 60 cycles, 110 volts or 280 turns for 25 cycles, 110 volts. Care should be taken in clamping the punch-

ings together; bolts made of non-magnetic material such as brass should be used, otherwise flux will leak through the bolts. The test consists in placing one pole face of the magnet over one side of the coil group, and holding a light piece of steel over the other side of the stator coil. If current flows in the coil, due to a short-circuit, the piece of steel will be attracted. It makes little difference whether one or more turns of the coil under test is short-circuited. These U-shaped punchings can easily be cut out from the laminated iron of discarded transformers. M. M. B.

1995—Photoelectric Cell—Please state how to construct what is called a photo-electric cell which will produce a current of electricity in proportion to the amount of light illuminating the cell, using either solar or artificial illumination (only excluding the infra-red rays which produce heat.) The cell to be excited only by the action of light rays. A. A. R. (MO.)

Electrochemical photo-electric cells may be constructed in the following manner:—(1) A silver electrode, well cleaned, is made anode in a solution of sodium chloride, $NaCl$, or potassium iodide, KI, until it is covered with a thin coat of silver chloride or silver iodide, respectively. When placed in a dilute sulphuric acid solution, the potential of this electrode varies with the intensity of light falling on it. For the second electrode, a similarly coated silver electrode kept dark is used. A lead electrode exposed may be used in place of the silver electrode kept dark, but in this case, the cell will develop a comparatively large e. m. f. when dark, and the illumination will cause but small changes in the e. m. f. (2) A copper electrode, slightly oxidized in a Bunsen flame, may be used in a one percent solution of sodium or potassium hydroxide, in place of the coated silver electrode with sulphuric acid as explained above. A lead electrode, not kept dark, may be used with a copper electrode the same as with the silver electrode, except that they must be used in the sodium or potassium hydroxide solution. The changes in e. m. f., produced by illumination in these cells, are very small and will be masked by galvanic polarization unless the e. m. f. is determined by a null method. J. S.

1996—Starting A Synchronous Motor with Full Field Excitation—I would like to know if a self-starting synchronous motor will start up and pull itself into step if the field is fully excited beforehand. If it does what will be its effect on the system? C. G. R. (COLO.)

The normal method of starting a synchronous motor is to short-circuit the field through the field rheostat set in the running position. The field is excitated only after the motor has approached within a very small fraction of synchronous speed. If the excitation be applied with the machine at rest the magnetic circuit will be saturated, which will reduce the torque and increase the kv-a. There will be a certain amount of extra surging in the alternating-current line, and current pulsations in the direct-current line, of slip frequency. After the motor has started there will be a counter torque developed due to excitation and under some conditions this torque might actually stall the motor at a low speed. E. B. S.

1997—Generator for Welding Outfit—About one year ago we bought a 15 kw, 60 volt, 250 ampere, direct-current generator for welding purposes. During the first six months the machine rendered excellent service, but during the last six months we have been having considerable trouble in keeping the voltage steady. The voltage jumps up and down, between five and ten volts, for no apparent cause. Sometimes our trouble starts at the begining of a run with or without load. Some days we have no trouble at all, while on other days it starts out without trouble, but, after operating for an hour or two, the voltage again starts to fluctuate. We have given the commutator, brushes, field coils and armature coils a close inspection but have found nothing wrong. I would be much obliged if you would inform me as to what might be the cause of our trouble. J. A. A. (NEW BRUNSWICK)

The information given is not complete enough to determine definitely the cause of your trouble. It is very probable, however, that the trouble is in the drive. Either the generator speed is not constant, or else it is too high. This set is belted. If the belt slips the generator speed would vary and fluctuations of voltage such as were mentioned would be noted. The cure in this case would be to tighten the belt or supply belt dressing. The speed of the prime mover may drop appreciably as the load comes on. In this case the generator voltage would drop as the load comes on, but would recover when the load is thrown off. This action is liable to make welding very difficult. If the generator is belted to an electric motor the generator may be driven above its rated speed at times. As a motor heats up, its speed increases. Possibly the pulley ratio is such that the generator speed at starting is correct. After running a while, the motor heats up and the speed of the set rises. With the speed above normal, the generator field is weakened to get the rated voltage. Running under this weakened field the generator may be somewhat unstable. The action then would be as follows: When the load is thrown on, and then off, the final voltage would probably not be the same as the original. Also a slight variation in the generator speed would affect the voltage to a great extent. If this is found to be the trouble change the pulley ratio to make the final generator speed the same as rated. S. H.

1998—Failure of Electric Car Center Plates—What is the cause of the failure of some electric-car center plates. The body plate is of malleable iron, finished. It rests on a finished brass ring, or washer, in the truck plate. When the car is loaded, the average pressure between them is a little over 1100 pounds per sq. in. I suppose as they wear the pressure tends to increase toward the inside and to decrease at the outside. As I understand lubrication, it will be impossible to lubricate these plates with oil, even though they are supplied with oil wells and grooves. In the case of plates which have not broken, the surface of the brass is bright. In the cases of breakage which I looked into, the downward-projecting base of the body plate had broken away from its bolting flange. The pocket of the truck plate seemed to have had no brass washer: the bottom of the pocket had a rather rough surface which seemed like that of iron, which could not be cleaned off with carbon tetrachloride. It could be scraped off, however, showing the brass beneath. I would be very grateful for answers to these questions (1). If a finished, malleable iron surface slides over a finished brass surface with a pressure of 1100 pounds per sq. inch, is the abrasion likely to be so severe as to leave a coating of the iron adhering to the brass? (2) What would be the resistance to such a sliding per sq. in.? (3) What is a safe intensity of pressure to allow in designing car center plates of these materials? (4) Is lubrication practicable? G. F. S. (MASS.)

1—Under the poor lubrication conditions existing in ordinary electric car center pin structures, a pressure of 1100 lb. per sq. in. is too high and abrasion is to be expected. 2—The coefficient of friction is indeterminate. Before cutting starts and with fresh lubricant forced between surfaces it will be very low, say not over five to ten percent. As abrasion starts it will rise to a high figure, dependent upon the condition of the surfaces. 3—In small double truck locomotives, unit pressures of from 300 to 360 pounds per sq. in. give satisfactory results with steel on steel. 4—With pressures of 300 to 360 pounds a fairly effective lubrication can be maintained. Oil will work itself over the surfaces, but grease has to be introduced under pressure. Both methods are used. G. M. E.

1999— Potentiometer Leads —The writer used copper wire to connect the thermocouples (imbedded in generator slots) to a switchboard potentiometer. I was told that the wire should be of the same material as the wires in the thermocouples imbedded in the slots, when a noncompensating potentiometer is used. Is this true? J. E. M. (MICH.)

A thermocouple generates an e. m. f. which is dependent upon the difference in temperature between the hot and cold junction. If copper wire is used to connect the themocouple terminals to the potentiometer, the cold junction of the thermocouple will be at the point of contact between the thermocouple and the copper leads. The temperature readings will then be in error by an amount equal to the difference in temperature between this cold junction and the temperature of the potentiometer, as indicated by its thermometer. T. S.

CORRECTIONS

In the Journal for January 1921, p. 15, the caption to Fig. 3 should read 70.7 percent in place of 70.0. On p. 16, the fraction in the first column of Table I should be inverted and should read $\frac{E_2}{E_3}$.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

JULY 1921

Stopping a Car by Braking with the Motors

Electric braking or "dynamic braking" as it is generally known is the indirect cause of a number of troubles supposed to be inherent with electric railway motors.. It is one of the causes of flashing, pitting of commutators and in some cases broken armature shafts and other mechanical failures. Burning of the reverser and other fingers and contacts occurs when the control is thrown off in the midst of a dynamic breaking period. A great number of reverser failures have been traced to this source and in some cases reverser finger burning has been practically eliminated by careful attention to the use of the dynamic braking feature.

HOW DYNAMIC BRAKING IS OBTAINED

In order to set up a dynamic braking condition, the connections must be such that the motors will act as generators employing the momentum of the car as a prime mover. To obtain this condition, the field connections must be reversed, with respect to the armatures, from the connections set up for normal running. This is done by moving the main drum of the controller to the "off" position, and moving the reverser drum to the reverse position, if the car is running forward, or

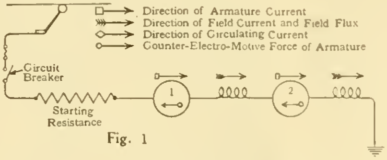


Fig. 1

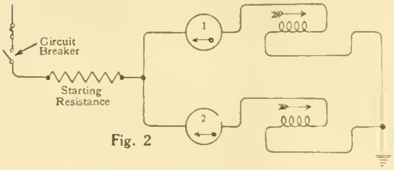


Fig. 2

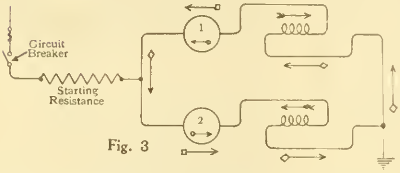


Fig. 3

to the forward position if the car is running backwards. If the car is headed uphill and starts to roll backwards, it is unnecessary to move the reverser drum.

In addition to setting up the proper connections of the fields in relation to the armatures, a loop circuit is necessary. On four motor equipments, the loop is always in exist nce, but on two motor equipments, it must be set up by means of the main drum of the controller which is moved to one of the parallel notches.

CONDITIONS INVOLVED IN A DYNAMIC BRAKING SET-UP

Figs. 1. 2 and 3 show the changes in connection from normal running to dynamic braking. Fig. 1 shows the normal running set up for the series position of the controller. The series position is chosen, as the diagram is somewhat simpler than the parallel and the conditions, as far as the changeover of circuits to obtain braking is concerned, are the same. In each case the circuit breaker is open. If it is not opened by hand, it will be opened by the heavy rush of current from the line when the main drum of the controller is moved to the parallel position after the reverser has been thrown. Fig. 2 shows the set-up momentarily when the loop between the two motors has been closed. Fig. 3 gives the final set-up when the motors are braking.

The counter-electro-motive force is the voltage which is set up in any motor in opposition to the line or trolley voltage due to the armature conductors cutting the field flux.

The residual voltage is the voltage set up at the armature terminals (the brushes) by the residual magnetism of the pole pieces when no current is flowing in the field coils.

The arrows in Fig. 1 show the direction of the current and the electro-motive forces in normal running. The arrow indicating the direction of current in the fields also indicates, in an indirect way, the direction of the flux through the poles of the motor.

In Fig. 2 the armatures and fields are drawn in the same relative position as in Fig. 1, but the field connections have been reversed and the loop between the two motors completed. It will be noted that the direction of the arrows is the same as shown in Fig. 1. This is done to indicate the condition just as the loop is completed and before the dynamic action has started.

The arrows in Fig. 3 show the direction of the current and the electro-motive forces after the dynamic braking is under way. The direction of the arrows in motor No. 2 has been changed.

WHAT CAUSES THE MOTORS TO GENERATE

There is one underlying principle in the construction of railway motors which permits dynamic braking under the conditions noted in Figs. 2 and 3. That is, no two motors can be built exactly alike in every detail.

When the power is shut off while the motors are running under the conditions as shown in Fig. 1, the direction of the flux of the fields due to the residual magnetism will be as shown by the arrows. In Fig. 2 the counter-electro motive forces and currents are in the same direction as shown in Fig. 1, hence, the flux of the fields are in the same direction. It is assumed that the construction of motor No. 1 is such that the residual magnetism builds up a higher voltage in the armature than motor No. 2. The voltage generated by each motor will be momentarily in the same direction as the counter-electro-motive forces shown in Figs. 1 and 2.

The higher voltage generated by motor No. 1 will force a current to flow through the loop and through the armature of motor No. 2 against the lower residual voltage, as shown in Fig. 2. This current flows in a direction which tends to weaken the residual field of motor No. 2 and strengthen the field of motor No. 1. During this short period. illustrated in Fig. 2, motor No 1 runs as a generator driven by the momentum of the car and furnishes power to motor No. 2 which tends to drive the car in the original direction. However the current flowing through the field of motor No. 2 wll quickly overcome its residual field and build up a field in the opposite direction. This will reverse the armature voltage and cause motor No. 2 to run as a generator which will force current to flow in the loop circuit in the same direction as the current generated by motor No. 1. Since both machines are now running as generators in series connection, short circuited on themselves and both generating current in the same direction, the current in the loop circuit will keep on building up until a balance between the motor voltage and resistance of the circuit is reached.

WHY CARE SHOULD BE EXERCISED IN USING THE DYNAMIC BRAKE

Due to the low resistance of the loop circuit and the relatively high saturation of the magnetic circuits possible with relatively high speeds of the armatures, very heavy currents are obtained. These currents, reaching a high value in a short period of time, cause sudden shocks to the electrical and mechanical parts of the running gear. As stated previously, flashing at the commutators occurs, and heavy strains are placed on the shafts, pinions and gears.

It is only under extreme emergency conditions, therefore, that dynamic braking should be used.

H. R. MEYER.

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The Gyro Stabilizer for Ships

The popular conception of stabilizing a great trans-Atlantic liner is entirely erroneous. There is inevitably pictured a titantic contest of the great rolling mass of the ship in the grip of something potentially as gigantic, struggling to subdue part of its motion. This conception also affords an explanation of the enormous stresses that are supposed to be involved in the process.

Now this is not at all true; it is much easier and simpler. We do not reduce the roll. We suppress it utterly by dealing only with beginnings. All rolling of ships is a gradual accumulation of individual wave increments. The slight extent to which any single wave rolls a ship is now well understood and all that is required is a comparatively small gyroscope that is capable of completely quenching this single increment.

A little gyro feeler or "control gyro", detects the incipient roll at its beginning and also shows its direction. This is the crux of the whole cycle; the rest is easy. Through a relay and motor, the large gyro is artificially precessed and delivers stresses of opposite sign to the ship.

To anticipate, however, one must apply the counter moments simultaneously to their being received from the sea. This would be impossible, were it not for the slow period of the ship itself, which gives an abundance of time to get precession under way and deliver the counter-stresses within the half period, continuing until the ship has actually been given a counter incipient roll, whereupon the electric contact in the control gyro is broken, indicating that that particular wave has been fully countered; meanwhile the ship, having received equal stresses of opposite sign, never starts to roll. This process involves not only a relatively small apparatus, but entails merely a trifling stress in the hull, that due to a single wave increment only, involving stresses of from one-sixth to one-tenth those present in a rolling ship.

To produce a ship that never rolls, regardless of weather conditions, becomes thus an extremely simple matter. The disappearance of roll is accompanied by a most satisfactory suppression of pitch. On most headings, more than 60 percent of the pitch disappears with the roll. An astonishing difference in headway also exists between a stabilized and unstabilized ship, repeated records showing between 10 and 12 percent. Recently the *Lyndonia,* a 100 percent stabilized ship, showed 14 percent gain, with the same full steam ahead, same weather conditions and same heading exactly. The importance of such a substantial gain cannot be neglected. It has been found through work done last autumn by Commander McEntee at the Naval Basin and other correlated results since obtained, that the stabilizer will make a saving of upward of 30 percent in heavy weather.

We are often asked, "Can large ships be stabilized?" The gyro stabilizer seems to be fitted by nature to deal with large ships. The stabilizing strength varies as the sixth power of the size. For example, a gyro twice the size of another, would have to rotate at only one-half the speed of the smaller one to stabilize a ship 64 times the size, i. e., 64 times the total periodic mass moments can be handled at a cost and weight of less than nine times.

The stabilizer is coming into its own. The gyro causes pounds easily to deliver tons of useful torque. Not only does it relieve the ship of all major stresses and increase its life, but it imparts marvelous comfort to the passenger carrier. Every voyage is a fair weather voyage—the occupants never seem in the slightest to realize their blessings until the stabilizer (precession motor) is turned off for two or three minutes to ascertain the true storm conditions and obtain records. After that—well, it is usually difficult to obtain permission to take another rolling record. Stabilizing prevents the serious depletion of cattle and horses in live stock ships. Through a variety of other important economies to which it directly contributes, it constitutes a definite dividend payer of large magnitude, paying for itself in a comparatively few trips.

E. A. SPERRY

Question Box Service

In this issue, we publish question and answer No. 2000, marking another milestone in a long period of service to our subscribers, which we have every reason to believe has been of great value to those who have used it.

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The Gyroscopic Stabilizer on the S. Y. Lyndonia

ALEXANDER E. SCHEIN
Engineering Div.,
Sperry Gyroscope Company

WHEN the Lyndonia left the Consolidated Ship Building Company at New York for her maiden voyage up the Eastern Coast last summer, she was hailed among yachtsmen as the most beautiful creation of the times. She is a masterpiece of the naval architect, yacht builder, and engineer. No expense has been spared to provide her with the latest improvements in design and equipment. Her machinery, rigging, interior fittings, or navigational instruments are of the latest type and altogether reliable. During the winter just passed there was added as part of her regular equipment a machine which has received considerable publicity in newspapers, and monthly periodicals during the last few months. This is the gyroscopic ship stabilizer. There is unfortunately much mystery about the properties of the gyroscope and the mention of a gyroscopic ship stabilizer brings up varied conceptions as to just what it is and what it does. The general opinion is that it prevents seasickness, and gives comfort to the passengers. There are however many other reasons why it is desirable to keep our ships on an even keel, in fact the necessity of a stabilized vessel is now clearly recognized.

FIG. 1—THE STEAM YACHT LYNDONIA

In the first place, why does a ship roll? Everyone agrees that waves cause a vessel to roll, but to get a firm understanding of the relation the stabilizer has to the vessel's roll, we must investigate a little further. It is one of the common beliefs that the stabilizer exerts tremendous forces on the ship and subjects it to great strains. An understanding of the following simple explanation will dispel all doubts about the small magnitude of the forces necessary to stabilize a ship.

Let us assume a ship to be on even keel and motionless, and a wave approaches broadside as in Fig. 2. The center of gravity of the ship remains fixed and the weight of the ship is represented by the force W acting down. But as the waves approach, the center of buoyancy shifts towards the wave crest, because more of the vessel is immersed on that side, and the buoyant force, which is equal to W, acts upward and is represented by B. It is evident that there is a couple tending to turn the ship and make it roll in the direction of the arrow. After the wave has passed to the other side of the ship and is traveling away, the couple will be acting in the opposite direction and the boat will tend to roll back. A series of these waves would cause the ship to roll more and more each time. No one wave, however, can impart any great amount of rolling to a vessel, because the effective wave slope, which is the factor disturbing the vessel's stability, is so small. The maximum roll increment due to any one wave may be from three to six degrees depending upon the type of ship and size of wave, among other things. Fig. 3 shows some rolling records taken on a gyroscopic recorder. They show quite clearly the gradual building up of the roll. If the period of roll of the ship is quite different from the period of the waves, there will be a building up of roll, and a gradual reduction of roll at frequent intervals, a phenomenon that in reality exists. It it were not for this condition, the synchronism of the natural period of roll and the period of the disturbing impulses due to the waves would soon build up a dangerous degree of rolling.

There are many unfavorable effects of free rolling. It is harmful to the ship structure. It causes severe stresses in the foundation of the machinery, boilers, stacks, superstructures and other heavy parts. The pounding of waves against the vessel's side is due to the waves being out of phase with the vessel's roll. There are other curious effects of rolling. A combination of roll and pitch causes yaw, which makes it very difficult to handle the ship and keep it on the proper course. The steering engine is in continuous use when yawing, and this is a twofold waste of power, to a small degree in the steering engine itself, and to a very large extent in the main propulsion engines, which have to drag the rudder through the water

when it is at some oblique angle. Recent tests conducted by Commander William McEntee at the Washington Navy Yard Tank show that a ship requires about one percent additional power for every degree roll—the extra power being necessary to maintain the same speed as if the ship were not rolling. All captains who have sailed with the stabilizer agree that they have been able to steer straighter courses and at faster speeds and with less helm with the stabilizer running than without it. On the run up from the West Indies this spring the Lyndonia increased her speed 1.5 knots by running the stabilizer and cutting the roll down from a total of 30 to 3.5 degrees. The recording chart of the gyroscopic compass showed less deviation from the course, and the helmsman reported practically no use of the rudder, whereas previously it had been a severe physical strain to stand watch at the wheel. The economic advantages of the stabilizer are therefore very important, to say nothing of the comfort assured to the passengers and ship's personnel. Rolling also decreases the efficiency of the propellers because of the tendency toward air cavitation on rolling vessels, especially those with twin or triple screws.

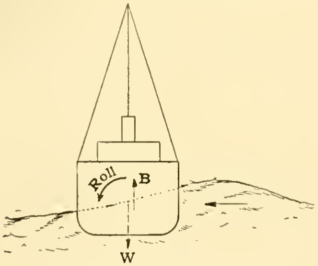

FIG. 2—EFFECT OF WAVE ON SHIP

The advantages of a stabilized ship were recognized early. Perhaps due to her maritime interests, Great Britain was the first to investigate the possibilities of ship stabilization. There appeared at various times inventions which involved the shifting of heavy weights back and forth over the deck to counteract the effects of the waves. The shifting was controlled by hydraulic pistons, valves and other devices and it was found that roll could be prevented somewhat, but that the large masses mowing in the proper direction at the proper time required delicate control mechanisms which were quite impracticable. Later there appeared the Framm Tanks,—U shaped vessels that extended down the sides of the ships and were connected at the bottom. They were partially filled with water which moved within the tanks from one side to the other and counteracted the waves. The movement of the water was controlled by valves, operated either by hand or mechanically and automatically, but it was found next to impossible to keep the proper relation between the ship's roll, the period of the waves, and the period of the water in the tanks, and that unless the exact relation was maintained the rolling would often be increased rather than decreased. It is interesting to note to what extent space and weight was devoted to stabilizing apparatus in past years. The present gyro stabilizer weighs only a small percentage of the ship's weight and takes but a fraction of the space of the Framm Tanks and other stabilizer devices. Framm Tanks may still be seen on some of the large liners coming into New York Harbor. They are not used and are only so much waste space. Among the simplest ideas to decrease roll was the bilge keel which is a fin-like projection extending along the sides of the ship below the water line. Bilge keels are put on almost every vessel launched and are quite effective in decreasing roll when the vessel oscillates through large angles, say down to a total arc of ten degrees; below this angle their effect could be overlooked altogether as their effectiveness is only proportional to the square of the velocity of roll. They are considerable drag on the main propulsion engines, the power consumption due to bilge keels being at least three percent of the total power of propulsion, even under the best conditions of trim, and with no pitching. The power losses of bilge keels in rough weather often reach as high a value as eight percent. A vessel equipped with a gyroscopic stabilizer permits the elimination of bilge keels,—the power saving, even in calm weather, by their elimination being considerably more than that required for the stabilizer in the roughest weather. Needless to say bilge keels were not put on the Lyndonia.

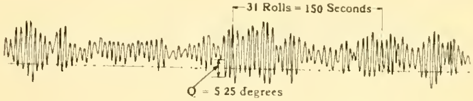

FIG. 3—ROLLING RECORDS TAKEN ON A GYROSCOPIC RECORDER

There next appeared, almost simultaneously the passive and active type gyro stabilizers. The passive type was invented by Dr. Schlick. It was called "passive" because it was not effective until the roll of the ship was large enough to "precess" the gyro. It, therefore, could not decrease all of the roll due to its sluggishness, but it was a long step forward. The great weights, and large space requirements of the old type stabilizers were replaced by a comparatively small wheel, the weight and effectiveness of which were multiplied by the speed of rotation and the speed of precession.

The Active Type Stabilizer was invented by Mr. Elmer A. Sperry of New York and was a very great improvement over the passive type in that it introduced ingenious controls which enable the stabilizer to become operative a fraction of a second after roll started; and the result is that roll can be decreased to very small angles. For practical purposes minimum stabilized roll less than two degrees total arc is not attempted.

So much for the history of ship stabilization. The fundamental principle of the gyro stabilizer is that

action of a gyroscope known as precession. Only a brief explanation will suffice to enable the reader to understand the action of the gyro stabilizer.

Fig. 4 shows a simple gyroscope which will illustrate the principle of the stabilizer. It consists of a rapidly spinning wheel with axis vertical, mounted in pivot bearings within a vertical ring. There are two trunnions on this ring forming a horizontal axis *XY*. If the trunnions *X* and *Y* are mounted in bearings the whole mass is then free to turn about the horizontal axis *XY*. Imagine the wheel to be spinning in the direction of the arrow on its rim, and that we apply forces at *X* and *Y*. The effect would be to turn the whole mass about a third axis *MN*. But just here is where the gyroscopic effect comes in. If we assume that the wheel is of sufficient size we can represent forces *X* and *Y* by two people, one of whom attempts to lift at *X* and the other depress at *Y*. There will be two very evident effects due to gyroscopic action. The first to be noticed is the great resistance the gyroscope offers to any effort to turn it about the axis *MN* by means of forces *X* and *Y*. The second effect is that point *A* will be seen to move away from us, and point

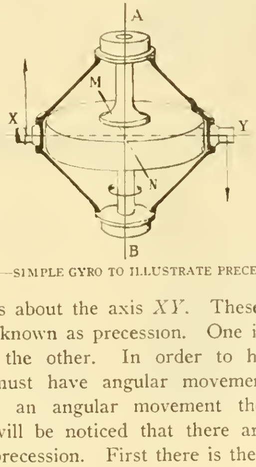

FIG. 4—SIMPLE GYRO TO ILLUSTRATE PRECESSION

B towards us about the axis *XY*. These two actions together are known as precession. One is never present without the other. In order to have resisting forces we must have angular movement, and conversely with an angular movement there must be forces. It will be noticed that there are three axes involved in precession. First there is the axis of spin, —the axis about which the wheel rotates. Secondly, there is the axis of spin at right angles to the first, about which the forces act. And third there is the axis of precession about which the gyro turns when forces are applied about the second axis. This third axis is perpendicular to each of the other two. The first axis is represented in Fig. 4 by *AB*, the second by *MN*, and the third by *XY*. Precession may therefore be simply defined as an angular movement accompanied by a resisting moment, both of which are at right angles to the axis of spin and to each other. This principle is made use of in the gyro ship stabilizer. Just how it is done is evident from Fig. 5, which shows the same gyroscope mounted in a ship. The axis *MN* is now the axis about which the ship rolls. As soon as there is any angular movement due to rolling, the gyroscope resists it by forces at *X* and *Y*, and at the same time precesses about the axis *XY*. If the direction of roll reverses the forces will also reverse and so will the precession about *XY*. The gyro automatically exerts forces in the proper direction and it is continually oscillating back and forth on the *XY* axis. In a general discussion about the ship stabilizer the turning movement of the gyro is known as precession, although as defined above precession strictly takes into consideration the forces acting. In this article precession will be taken to mean the angular motion of the gyro, and when the forces are referred to, the term will be gyroscopic force or gyroscopic moment. This separation of the two actions simplifies the discussion and is the common practice when speaking of stabilizers.

In Fig. 5 is shown the simplest form of ship stabilizer. In actual design the rotating wheel or rotor, is mounted in bearings and enclosed in a casing. On this casing there are two gudgeons corresponding to points *X* and *Y* through which the forces are transmitted to the ship. It remains only to limit these

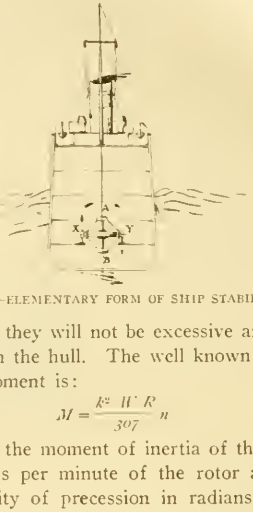

FIG. 5—ELEMENTARY FORM OF SHIP STABILIZER

forces so that they will not be excessive and cause undue stresses in the hull. The well known formula for gyroscopic moment is:

$$M = \frac{k^2 W R}{307} n$$

where k^2W is the moment of inertia of the rotor, R is the revolutions per minute of the rotor and n is the angular velocity of precession in radians per second. The moment will be in foot-pounds. If we omit the complexity of mathematical expressions the above moment is approximately equal to the tilting moment produced by the maximum effective wave slope, and if such a moment were applied to a non rolling ship during the period of oscillation it would cause the ship to roll an amount about equal to the maximum roll increment. The stabilizing moment is therefore only slightly greater than the natural effect of the waves causing the ship to roll, and in the case of the Lyndonia is only about 375 000 ft. lbs.

From the formula it is seen that we can control the magnitude of the gyroscopic moment by varying either R or n. It would be impossible to vary R quickly and easily. But with R constant it is an easy

matter to vary n and hence M. Stabilizers are therefore designed for some known value of R which will not overstress the wheel, and the gyroscopic forces transmitted to the ship are limited by limiting the speed of precession by mechanical brakes or other means. This type of stabilizer is known as the passive gyro stabilizer. It uses the force of the waves to start gyro precessing, and mechanical brakes and suitable control pistons and levers to control within close limits the speed of precession. Due to the fact that the mass of the casing and wheel is necessarily large it takes several seconds to get the speed of precession up to normal velocity and therefore the ship has gained considerable roll before full stabilizing is obtained. The passive type stabilizer cannot decrease the roll to less than six or seven degrees.

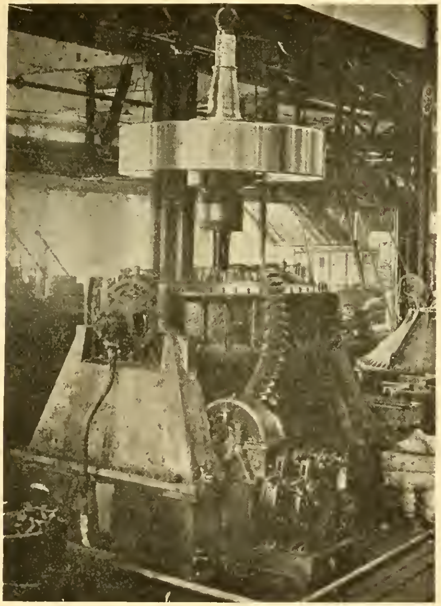

FIG. 6—ROTOR WITH SHAFT STUBS BOLTED IN PLACE

The Active Type Gyro Stabilizer practically anticipates the waves and starts stabilizing when the ship has barely moved. The sensitive element that is responsible for this action is known as a control gyro. It is a small gyroscope suitably mounted in bearings, casing, and frame which does not weigh over 150 pounds complete for even the largest vessels. The wheel is turned by an electric motor at five or six thousand r.p.m. The whole unit can be made so sensitive that it will indicate the ship's roll a fraction of a second after the roll starts. The indication of roll is transmitted electrically to control panels which operate a precession motor. This motor is geared to the main stabilizer unit and starts precession of this unit immediately, instead of waiting for the waves to do so. The result is full stabilizing forces about 1.5 seconds after the roll starts and the ship can be stabilized to 1.5 or two degrees roll on each side of the mean position.

The following paragraphs cover some points of the technical design of the active stabilizer for the steam yacht Lyndonia. This is the first ship to receive a stabilizer since the United States entered the World War. It is a vessel 320 feet long overall, 30 feet beam, and displaces about 1100 tons. The normal speed is 13 knots with two triple expansion steam engines.

In designing a stabilizer for a ship there are certain characteristics to be taken into account. They are displacement, metacentric height, period of roll, and roll increment. Displacement is expressed in long tons of 2240 lbs. each; metacentric height is expressed in feet, and period of roll in seconds. The first is easily determined from the ship itself or from its builders. The second is often furnished by the naval architect but must be determined by a heeling test later. The third is most easily determined by an instrument known as the Roll and Pitch Recorder. This is a gyroscopic instrument which makes a graphic record of the vessel's roll and pitch together with a time indication by means of which the period of roll may be estimated. Fig. 3 shows such a record. The curve is that of the vessel's rolling, and the bottom line with jogs is the time curve. A jog occurs at every ten seconds interval. The period may be estimated by counting off a number of complete rolls and noting the time. Roll increment, which was the fourth item above is the number of degrees increase in roll in a single complete roll of the ship. An example of roll increment is given in Fig. 3 at the point marked Q. In designing a stabilizer the maximum roll increment is necessary because the stabilizer must be made to have a roll quenching power at least equal to the maximum roll increment, or full stabilization could not be obtained. The stabilizer would be of little use if a single wave could roll the ship more than the stabilizer could take care of. The roll quenching power depends upon the characteristic product $D\ T\ H$, displacement times period times metacentric height. The following characteristics were assumed for the Lyndonia before the ship was launched.

$D = 1000$ tons
$T = 7.5$ seconds
$H = 3.2$ feet
$DTH = 24000 =$ characteristic product

After launching with the stabilizer in place, the characteristics were found to be

$D = 1100$ tons
$T = 10.5$ seconds
$H = 2$ feet
$DTH = 23000 =$ characteristic product

The original figures were somewhat in error but the stabilizer, which was designed on $DTH = 24\,000$ was about five percent oversize according to the final figures. The maximum roll increment was also somewhat smaller than expected and this fact provides further margin of stabilizing power.

The design of the rotating wheel is dependent entirely upon the assumed values of DTH and the roll quenching power. In the case of the Lyndonia a rotor with $k^2WR = 165\,000\,000$ was found to be necessary. The rotor finally designed had a moment of inertia of $k^2W = 112\,000$ ft.² lbs. and a speed of rotation of $R = 1500$, giving $k^2WR = 168\,000\,000$. Fig. 6 shows the rotor with its shaft stubs bolted in place. There are many factors entering into the design of such a rotor. The speed of rotation is limited by the peripheral velocity of the rim, which ought not to exceed 32 000 feet per minute or the windage losses will be excessive. The shape of the rim and web section is another item that depends upon windage and stress considerations. Tangential fibre stresses at full speed of rotation are not over 12 000 lbs. per square inch. The 6.5 ft. diameter rotor is a solid steel forging and the shaft stubs are nickel steel, the whole rotating element as shown in the photograph weighing about 22 000 lbs. Needless to say the balance of such a unit must be of the highest order and perfection. The balance of the Lyndonia rotor was made on a machine built and designed by the Westinghouse Electric and Mfg. Company. Remarkably good results were obtained on this machine.

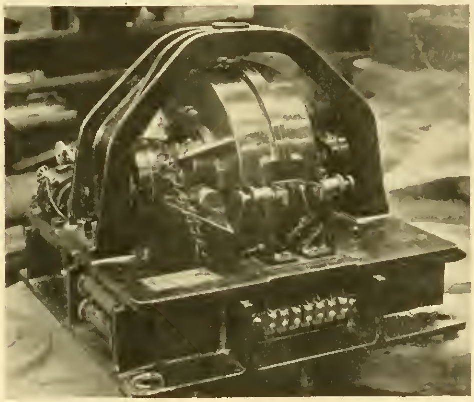

FIG. 7—CONTROL GYRO

Coincident with a good balance there are other precautions which must be observed to insure the successful operation of the stabilizer. The journals and bearings have specially prepared surfaces and their design has been carried to an extreme degree of accuracy. The large gyroscopic loads could not be carried on any type of bearing which is common practice today in similar work,—that is with the same pressures and journal speeds. The main bearings on the stabilizer in question carry 800 lbs. per square inch of projected area and under test conditions successfully carried 1000 lbs. per square inch. On another stabilizer with similar bearings, loads of 1400 lbs per square inch were carried successfully. These loads gradually increase from zero to a maximum and are not suddenly applied. This will be evident from consideration of the formula for gyroscopic moment which varies as n, the precession velocity. The thrust load of the rotor is carried on a Kingsbury bearing which gives silent and very efficient operation.

On the left in Fig. 6 may be seen one of the gudgeon bearing housings. Two of these bearings form a horizontal axis about which the entire casing precesses, and it is through these bearings that the gyroscopic stabilizing forces are transmitted to the ship structure. These are roller bearings and carry a maximum load of 68 500 lbs., consisting of the gyroscopic force, 48 000 lbs. and half the gyro unit weight, 20 500 lbs.

In the same photograph may be seen a large gear mounted on the gyro unit. This is the precession gear which meshes with a worm gear reduction unit and through which the speed of precession is controlled. The precession motor is connected to the gear train with a 100 to 1 gear ratio. The speed of precession of the main gyro depends upon the period of roll of the ship. The total arc of precession for full roll

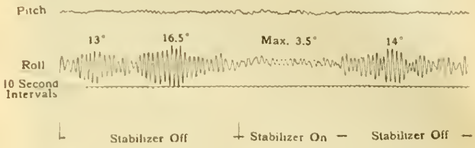

FIG. 8—ROLLING AND STABILIZING CURVES FROM LYNDONIA

quenching power is 120 degrees; 60 degrees each side of the vertical. The gyro must be made to precess through this arc in the same time the ship rolls from port to starboard, or starboard to port. The relation between period of roll and velocity of precession in r.p.m. is approximately $N = \frac{60}{T}$. In determining the velocity of precession for the Lyndonia stabilizer a period $T = 9$ seconds was assumed with a variable range to cover any possibility of error in data. With nine seconds period, the speed of precession would be 7.3 r.p.m. corresponding to a precession motor speed of 730 r.p.m. In Fig. 6 may also be seen the mechanical brakes at the right of the center. These are mounted on the worm shaft also, and are used to stop the precession quickly at the end of the precession arc.

The stabilizer equipment is practically independent of the ship power. A steam turbine-generator set provides all electrical power necessary to operate the equipment except for small excitation and control gyro current. The gyro may be brought up to full speed in one and one-half hours depending upon the current input to the motor. This does not mean that the stabilizer equipment is inoperative for 1½ hours. Stabilizing can start when the gyro is at about three-quarters full speed, and can continue while the gyro is being brought up to speed. The precession motor is controlled from a relay starting panel, which in turn

is energized by the action of the control gyro. The control gyro, precession motor and magnetic brakes constitute partly the controlling device which distinguishes the active and passive type gyro stabilizer.

The photograph of the control gyro, Fig. 7 shows the moving contactor which completes the circuits to the relay starting panel by moving left and right as the roll of the ship precesses the small rotor. This rotor is mounted with horizontal axis thwartships. Roll to port or starboard will therefore cause the gyro to precess about a vertical axis to port or starboard, depending upon the direction of rotation of the wheel. The control gyro is the sensitive element or brain of the entire equipment. It senses the roll of the ship a fraction of a second after motion starts and communicates the direction and amount of roll to the precession motor. Immediately the main gyro exerts its forces to

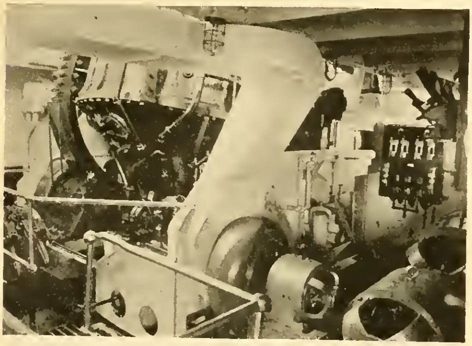

FIG. 9—INTERIOR VIEW OF STABILIZER COMPARTMENT ON THE LYNDONIA

prevent the roll, irrespective of direction. The control gyro never makes a mistake in direction, always starts precession about a half second after roll begins, and stops precession about a half second before roll stops. The control gyro and the other control mechanisms on the Lyndonia are sensitive to three degrees total roll. By increasing the gyroscopic effect and the directive effect of the control gyro it would be possible to stabilize to less than three degrees total roll, provided also that the precession motor were increased in capacity to be able to accelerate the main gyro more quickly. This however is not necessary, as three degrees total roll is almost imperceptible unless one is looking for it.

There are many interesting features of the stabilizer on this yacht. Being as it is, slightly oversize, it has sufficient capacity to handle even the most severe seas. In fact, for general service, it is run at about three-quarters full speed of the rotor, and has been found to give entirely satisfactory results. The rolling and stabilizing records taken on the trial trip and reproduced in Fig. 8 were obtained with three-quarters speed of the gyro. A roll of thirty degrees was reduced to four maximum. Even if the roll has been very much greater the stabilizer would have kept the boat within the same limits. It matters not how great the roll, if the stabilizer has a roll quenching power greater than the roll increment due to a single wave, it will gradually reduce that roll down to the same small amount. And it will do this without applying any more than the normal stabilizing forces to the ship, because the speed of precession being maintained constant, the gyroscopic moment must also be constant. This moment is perfectly determinable, and the bearings, gudgeons, and foundations have been designed to suit. By controlling the speed of the gyro, the operator has within his power the adjustment of the stabilizer to the sea conditions which is an important feature because it means a saving in power.

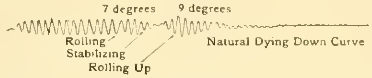

FIG. 10—ROLLING CURVES OF THE LYNDONIA AT ANCHOR IN STILL WATER

The stabilizer action can be reversed, rolling the ship, instead of stabilizing.

About 90 percent of the total power necessary to run the stabilizer is used in spinning the rotor, so that even small changes in speed mean considerable variation in power. To reduce the spinning horsepower as much as practical the rotor is run in a fifteen inch vacuum maintained in the casing by a small air pump. At full speed the power required for spinning is about 33 hp. The power for precession is almost negligible, because the waves tend to precess the gyro naturally, the only power necessary being that required to assist the waves in bringing the gyro up to full speed of precession and this does not average over four hp.

It was the enthusiastic report of Captain Rich and the other officers of the Lyndonia that the stabilizer did all that was expected of it. At no time were the decks ever awash as long as the stabilizer was in operation, but on one occasion without the gyro working, the stern rolled under and shipped two feet of water. Steering was always a pleasure when the yacht was stabilized and the equipment is now considered so necessary that they never leave port without it running.

The Construction of the Lyndonia Stabilizer

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THERE was a time when the stabilization of ships was considered solely for the comfort of the passengers and the ship's personnel. This truly was worth considering for all types of vessels, commercial, naval and pleasure, especially in the later designs of vessels which have been built for speed, resulting in narrow beams and fine lines. Today many other reasons have developed why a vessel should be stabilized, such as relieving strains in the ship's structure and machinery, for operating the ship more economically, for maintaining a more nearly straight course and in the case of naval vessels, for aiding in gun fire. A stabilizer has just been installed on the Yacht "Lyndonia," the purpose of which is primarily the comfort of the passengers.

The Lyndonia stabilizer consists of a vertical rotor made up of a solid forged steel disc wheel 6 ft. 6.5 in. diameter having a rim 17.5 in. wide and 11 in. thick. The disc portion has two circular flanges, one on each side to which are attached the shaft stubs. On the lower stub just above the journal is mounted a spinning motor which revolves the rotor.

The entire rotor is surrounded by a casing in the shape of two frustums of cones with their bases together. The main portion of this casing is made up of three separate steel castings, a center casing or belt which encircles the rotor rim and an upper and lower casing which make up the conical sections. It is in these latter sections that the main rotor bearings are carried. These bearings as well as the journals, which have supported loads as high as 1200 lbs. per square inch of projected area at a journal speed of 50 feet per second, have received special attention in regard to machining to insure safe operation under these loads. The bearings are of the solid spherical seated type in order to provide self-aligning features to compensate for the shaft deflection between the rotor and journal as the stabilizer is precessed and the gyroscopic forces set up. In connection with the bearings it is interesting to note the conditions under which they operate. When the gyroscope is precessing fore and aft, the major forces act athwartship stabilizing the vessel; on the other hand when the stabilizer is not precessing, but the ship is rolling, the forces act fore and aft tending to cause the vessel to pitch. Thus there are four major bearing surfaces on which very heavy loads are imposed, with the greater ones athwartship due to the fact that the stabilizer precesses at a greater angular velocity than the ship would roll. Naturally when the ship is rolling heavily and the stabilizer is spinning it is also precessing, thus the athwartship section of the bearing is the working portion that is in use most of the time. With these facts in view the surface of the bearing is divided into four sections with the oil grooves between each section. Each athwartship section extends through an angle of about 130 degrees and each fore and aft section through about 30 degrees the remaining angle being taken up by oil grooves. Each of these sections were scraped separately. During the first run with these bearings, while they were being worked in, a difference of oil pressure or an oil pressure of 10 lbs. above the vacuum obtained in the casing was maintained on them (The entire casing and oiling system is under a partial vacuum of 15 to 20 inches). With this condition the temperature rise through the bearing averaged from 15 degrees to 20 degrees. This temperature difference existed while the gyro was not precessing but while it was slightly inclined, the reaction on the bearings amounting to only about 50 lbs. per square inch of projected area. This load however was actually concentrated on a small area between the oil grooves in the fore and aft sections of the bearing. As soon as precession was started and the loads applied to the usual working surfaces, even though the pressure per square inch of projected area amounted to 900 to 1000 lbs., the temperature rise through the bearing fell off to 10 degrees as a maximum. This was due primarily to the fact that there was a large bearing surface and that the pressure was first on one side of the bearing and then diametrically opposite as the unit precessed every four seconds, thus affording ideal conditions for flushing the working surfaces with cool oil.

When operating at speeds above 75 r.p.m. the weight of the rotor is carried by a Kingsbury thrust bearing at the bottom of the lower journal; at speeds lower than this, the weight is transferred to a ball thrust bearing. This procedure is resorted to in order not to wipe the Kingsbury thrust shoes before an oil film has been established beneath them.

On the bottom of the lower casing are mounted the caps containing the thrust bearings, the construction of which is shown in Fig. 1. At the top of the left hand portion of this figure is shown the main rotor journal into which is screwed the Kingsbury thrust collar. Below this collar are the thrust shoes carried on two leveling plates. Each of these leveling plates is supported on a knife edge, the knife edge acting as a support for the top plate being at right angles to that for the bottom one.

Below the Kingsbury thrust bearing is the ball thrust bearing which is used when starting or stopping the rotation of the stabilizer wheel. It will be noted that this bearing is supported from the bottom of the cap on a free sliding piston. When the weight of the rotor is to be transferred from the Kingsbury thrust

bearing to the ball thrust bearing, an oil pressure of approximately 1005 lbs. per square inch is built up in the cylinder below the piston by means of the hand operated hydraulic jack pump shown at the right. This pressure raises the ball bearing bodily until it comes in contact with the upper ball race after which it lifts the rotor itself to the extent of about 0.005 inch which leaves sufficient clearance between the Kingsbury thrust bearing shoes and collar for starting In conjunction with these hydraulic features it will be noted on the outside of the cylinder there is a large square threaded nut which in turn has a gear cut on its periphery that meshes with a small pinion controlled by a hand lever on the outside of the cap. As the ball bearing is being jacked up, this lever is swung around, causing the nut on the outside of the hydraulic cylinder to follow up the flange of the piston. The bearing is raised until the outside hand lever is stopped by a lug on the lower cap. When the lever is in this position the ball bearing has been raised sufficiently to take the load off the Kingsbury bearing. It should also be noted that with this hand lever in this position

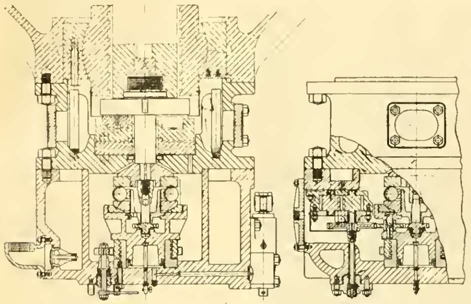

FIG. 1—THE KINGSBURY AND THE BALL THRUST BEARINGS

the oil pressure may be relieved and the ball bearing will still be held in the same position by the nut. For lowering the bearing the reverse operation holds.

On the right of Fig. 1, is shown the gear type oil pump driven from the rotor. This pump supplies sufficient oil to the system when the rotor is spinning at the normal speed of 1500 r.p.m. but for other speeds the auxiliary pump is required. The extension shaft extending down through the cap is for the purpose of obtaining the speed of the rotor.

The whole gyro unit, consisting of rotor, bearing motor and casing is supported on gudgeons or trunnions cast and turned on the center casing with their axis at right angles to the axis of spin of the rotor. The bearing itself consists of a roller bearing having its outer race turned spherically. In addition to serving as a bearing, this gudgeon also furnishes space for the swivel joint through which the lubricating oil is passed to and from the cooler, strainer and auxiliary oil pump. As the case is precessing or oscillating about the trunnions it is of course necessary to have this swivel joint to get the oil from an oscillating member to a stationary member. The construction of this swivel is obvious when it is considered that all portions outside the roller bearing are stationary. It is this outside housing that is bolted to the ship's structure and through which the gyroscopic forces are transmitted from the gyroscope to the ship.

The starting of the precession of the stabilizer is accomplished by means of a so called precession motor and a precession gear. The precession gear is a double reduction, the first being through a worm and worm wheel and the second through a straight spur gear. The pinion of the spur gear meshes with the large gear encircling the stabilizer casing, shown in Fig. 2.

In order to check the precession of the gyro in case of accident to the precession gear when the ship is rolling heavily a buffer is provided. This is nothing

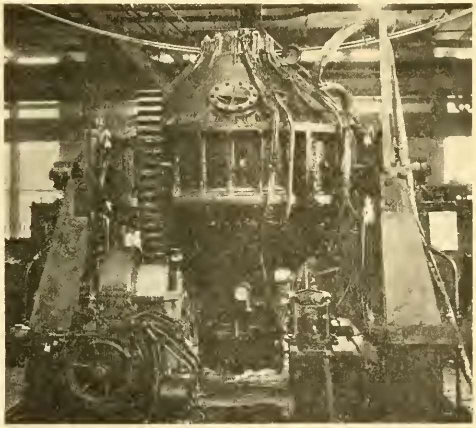

FIG. 2—LYNDONIA STABILIZER ASSEMBLED FOR TEST

more than a shock absorber consisting of a coiled spring, against which a hammer or projection on the center casing strikes as it precesses beyond a certain set angle.

The entire casing and oiling system is air tight and operates under a partial vacuum of from 15 to 20 inches. With this partial vacuum there is a saving of about 20 h.p. A higher vacuum would be carried except for lubricating and motor difficulty. The vacuum is obtained by means of a small air compressor with its valves reversed and driven by a 1/2 h.p. motor. The motor is controlled by a switch that closes when the vacuum falls to 15 inches and opens when it reaches 20 inches. With this arrangement and a reasonably tight system the motor operates about five minutes every half hour.

The Electrical Equipment for the Lyndonia Stabilizer

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THE rapidly increasing use of the gyroscopic stabilizer has led to the development of electrical apparatus designed especially for this service. The principal operations of stabilizing a vessel are controlled by two motors, the spinning motor and the precession motor. The spinning motor, as its name implies, keeps the rotor spinning about its axis, which is normally vertical. The precession motor, operating through a worm gear, precesses the stabilizer at intervals corresponding to those of the waves. The combination of these two rotations, sets up a gyroscopic couple at right angles to both of them. This couple, transmitted through the gudgeon bearings to the ship structure, counteracts the effort of the waves to make the ship roll.

The complete electrical equipment required by the stabilizer consists of the following:—

1—Control gyro,
2—Precession motor,
3—Generator to supply power to precession motor,
4—Magnetic brakes for precession system,
5—Motor driven vacuum pump,
6—Control panels,
7—Spinning motor,
8—Generator to supply power to spinning motor.

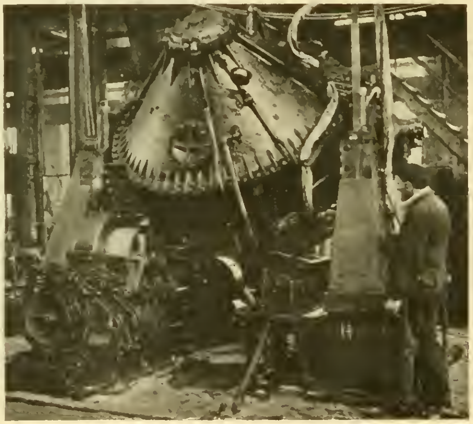


FIG. 1—STABILIZER ON TEST FLOOR

The control gyro, upon which depends the proper time of application of the forces of the stabilizer, carries a contact tip projecting between two stationary contacts mounted on the base of the unit, these contacts being spaced about one-half inch apart. Control circuits are led from these contacts to the operating coils of the magnetic contactor switches which control the precession motor.

The precession motor of the Lyndonia is an 8.5 hp, 115 volt, 720 r.p.m., compound wound machine of the standard industrial type, except for the moisture proof impregnation and non-corrodible fittings for marine use. As shown in Fig. 1, the power from this motor is transmitted through a worm gear reduction unit to the large half gear on the gyro casing. The function of this motor is to bring the gyro to full precession speed with the least possible delay, after the ship starts to roll enough to operate the control gyro. Upon its ability to do this depends, to a great extent, the efficiency or nearness of approach to complete stabilization. The rating given above is based on the r.m.s. load over one complete precession cycle.

Power is supplied to the precession motor by a compound wound, direct-current generator driven by a steam turbine, which also drives an alternator for supplying power to the spinning motor. The direct-current generator furnishes power to the precession motor only and therefore has the same rating.

The main control equipment is very simple. For the precession motor, a cabinet type contactor panel is used. This panel carries the contactors for starting and reversing, including one accelerating contactor, as well as an overload relay, and self-contained starting resistances. This panel is completely controlled by the control gyro. In addition to this, a small switchboard panel is mounted at the side of the stabilizer compartment, just above the turbine generator set. This panel carries a carbon circuit breaker for the alternating-current circuit, necessary meters and knife switches for the various feeder circuits, and the generator field rheostat.

The large fly wheel of the gyroscope, operating in a vacuum, would run for several hours after the power was shut off from the driving motor, unless some external means of slowing it down was provided. This would, of course, be undesirable at all times, and especially so in case any bearing trouble should develop. A novel braking arrangement has therefore been developed for quickly stopping the fly wheel, whenever this becomes desirable. This arrangement has proved very effective in service, permitting the fly wheel to be brought to rest in a small fraction of the time that would be required if it were allowed to run until stopped by friction and windage only.

On this installation, the gyro rotor acts as a flywheel in balancing the load on the turbine. When the precession motor is started, it throws a peak load on the turbine, causing it to slow down. As soon as the speed drops below the synchronous speed of the spinning motor, the latter operates as an induction genera-

tor, driven by the gyro rotor, thus assisting the turbine to drive the direct-current generator during the overload. It will be noted that the stabilizer equipment is

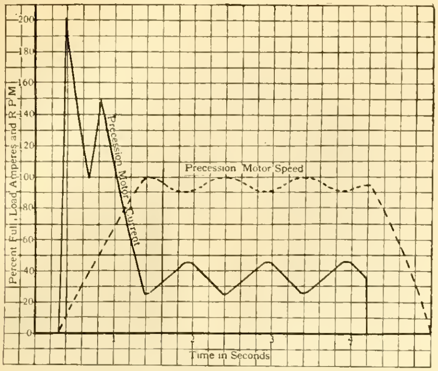


FIG. 2—PRECESSION MOTOR LOAD AND SPEED CURVES

self-contained electrically, with the exception of the small amount of current required for the control circuit of the control gyro and its motor.

OPERATION OF THE PRECESSION SYSTEM

Curves of the precession motor armature current and speed plotted against time in seconds, based on a normal period of roll of the vessel of ten seconds are given in Fig. 2. Assume that the ship begins to roll. About one-quarter second later, the control gyro closes the control circuit to the line contactor, causing it to close and connect the precession motor in series with the starting resistance and brake coils to the power supply. Thus the brakes are released and the motor starts. The motor must accommodate 200 percent full load current at start. The current rapidly drops to the full load value as the motor speeds up. Then the accelerating contactor closes, cutting out the starting resistance and the series field of the motor. This causes the current to increase again to about 150 percent full load and the motor quickly comes up to speed. The series field of the motor is used on the first step to give good starting torque and is then cut out in order to give better regulation during the remainder of the cycle.

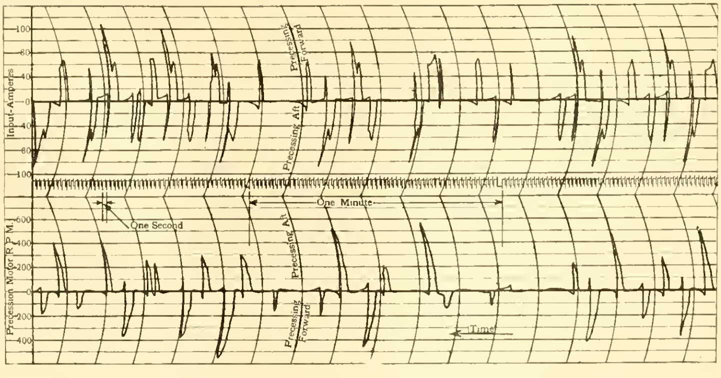


FIG. 3—GRAPHIC METER RECORDS OF PRECESSION MOTOR CURRENT AND SPEED

The gyro has now reached a precession speed which it tends to accelerate further by virtue of the forces exerted on it by the ship. Thus the load on the precession motor rapidly decreases. The brake coils are designed to hold the brakes released, or free, until the precession motor current drops to approximately 25 percent full load. Then the brakes set, throwing more load on the precession motor and slowing it down. The current then increases until approximately 45 percent full load is reached, when the brakes again release. Thus the precession speed is maintained between certain limits during the remainder of the cycle, as long as the control gyro keeps the contacts closed. Just before the end of the roll, the control gyro opens the contact, cutting the power off the motor and brakes, causing them to set and rapidly bring the precession to a stop. Then as the ship starts to roll to the other side, the same operation takes place in the reverse direction. This constitutes a complete cycle.

Fig. 3, shows sections of graphic meter charts, giving simultaneous values of precession motor current and speed taken during the trial trip in January of this year. These were taken before final adjustments were made in the starting resistance to bring the current peaks more nearly equal. However, they will serve to show what a widely varying load this motor must carry.

THE SPINNING MOTOR

The spinning motor is the most special part of the electrical equipment and is of interest both on account of its construction and the duty it has to perform. The best design of the stabilizer required that the spinning motor be located on the shaft of the rotor between the flywheel and the lower guide bearings. Therefore a motor was required that could operate continuously in a partial vacuum and also have such proportions that its rotating element could be mounted directly on the rotor shaft. This motor was to be able to break away and accelerate a 22 000 lb. rotor from rest to full speed, then spin the rotor continuously at 1500 r.p.m.

About 33 hp is required to spin the rotor at 1500 r.p.m. under partial vacuum. This power is required

to overcome bearing friction and windage and drive the small geared oil pump. It is constant whether the stabilizer is precessing or not except for a slight fluctuation of the friction losses due to the pressure changing on the bearings as the stabilizer is precessed. On account of the momentum of the rotor this fluctuation is not perceptible on an ammeter in the circuit, but is indicated by a slightly increased power consumption.

If the same motor is to be used to start and accelerate the rotor that is to be used to spin it, something must be done to bring the torque requirements of the different parts of the duty cycle somewhere near the same value. In designing the stabilizer every effort was made to make the starting, or break away torque as low as possible. How successful these steps have proved may be judged from the results of a series of starting tests on the Lyndonia stabilizer where the 22 000 lb. rotor was started from rest a number of times by hand. The average break away torque obtained from these tests was 40 lbs. at one foot radius. These tests represent very nearly ideal conditions however, and the spinning motor was designed to have a starting torque of 80 lbs. to care for cases when the bearings are worn or slightly rough.

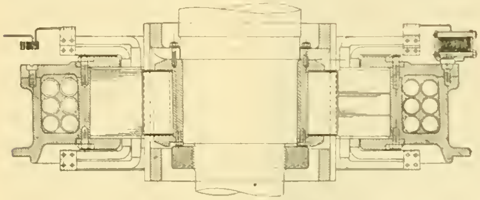


FIG. 4—CROSS SECTION OF SPINNING MOTOR

The inertia of the rotor is so large that it would require a prohibitive torque to accelerate it to speed in a short time. By lengthening the time of acceleration this torque can be reduced. If the acceleration period should be lengthened until the torque required was equivalent to a 50 percent overload torque on the motor, the time of acceleration would be about 75 minutes. This figure will, of course, vary to some extent with different sizes of stabilizers.

There is no serious objection to this length of time of acceleration on a stabilizer, as a rough sea can always be anticipated long enough ahead to prepare for it. Also it is not necessary to have the rotor at full speed before starting to stabilize. The acceleration period is the most difficult part of the duty cycle of the spinning motor and is the principal consideration in the selection of the motor to be used.

There are several types of motors that might be adapted to this service, among which are:—

1—Direct-current shunt motor.
2—Wound-rotor induction motor with external resistance.
3—Squirrel-cage induction motor using variable primary frequency to get variable speed.

After considering these three types carefully the squirrel-cage motor was selected as being the most suitable one for this application. The simplicity and ruggedness of the rotor is of special advantage here, as the heat from nearly all of the rotor losses must be conducted away through the shaft. The stator is naturally compact and can be easily adapted to water cooling. The method of starting with low frequency and voltage, and accelerating by raising the frequency and voltage together gives the best current and torque conditions in the motor that can be obtained. Furthermore the squirrel-cage motor can be designed to have very desirable performance characteristics at both low and high frequency.

The motor used on the Lyndonia is a three-phase, 50 cycle, four-pole, 1500 r. p. m. vertical squirrel cage induction motor, with a frame arranged for water cooling. The frame is split horizontally to permit the cooling coil to be assembled inside. At the water port the frame is widened to permit a double bend in the ends of the cooling coil. Figs. 4 and 5 show the frame with the cooling coil in place. The gyro casing is

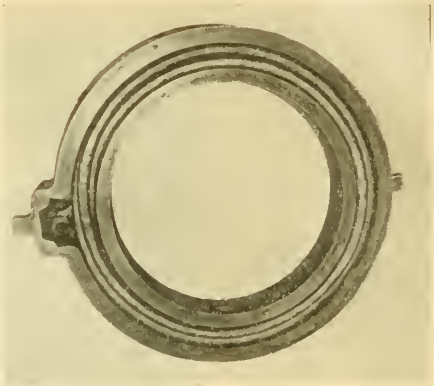


FIG. 5—FRAME WITH COOLING COIL IN PLACE

drilled at a point directly under the water port in such a manner that the inlet and outlet pipes can be tapped directly into the ends of the cooling coil from outside the stabilizer. This construction removes all chance of trouble from internal piping, and makes the pipe fitting very simple. The cover fits over the open top of the body and provides support for the end plate and primary connections. The cooling coil consists of several turns of one inch copper tubing arranged in a double coil, inside the U of the body. After the coil is in place, the remaining space inside the frame is filled with babbitt metal, making a solid metal path for the heat to flow from the frame to the cooling water. The primary core fits snugly into the frame, and is held in place by a key and bolted on end plates.

The primary winding is made up of separately insulated copper straps. These conductors form a double layer group winding, similar in electrical characteristics to the usual induction motor winding when partially closed slots are used. The end turns are,

however, bent back to lie as closely against the end plates as possible. To get the coils still more compact they are made in halves and joined at each end by figure 8 connectors after they have been placed in the slots. The cross connections are of strap and are nested on top of the motor just outside the coil ends, as shown in Fig. 6.

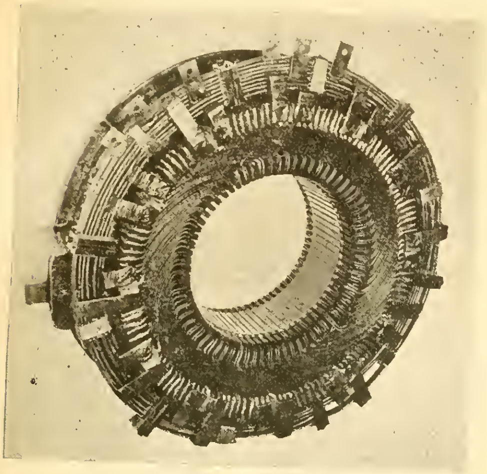


FIG. 6—BOTTOM VIEW OF SPINNING MOTOR STATOR

The assembled stator is treated with several coats of an insulating varnish which fills the air spaces between the coils. This greatly improves the thermal conductivity between the coil ends and the endplates. Another no less important result of this treatment is the protection of the insulation from the oil and moisture which are apt to be present under service conditions. As can be seen from the illustrations, the stator is very compact, with the cooling coil close to the center of the section.

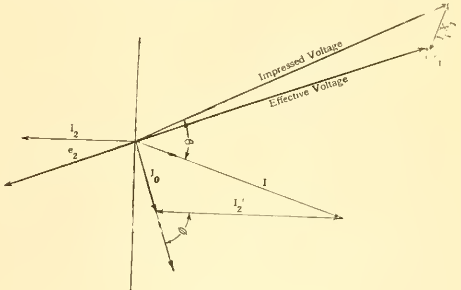
The leads from the motor are brought out of the casing through a terminal port plate. Six copper studs insulated by micarta tubes extend through this plate, being held in place and the openings sealed by stuffing glands filled with packing, saturated with shellac. Six leads were brought out so that the connections could be changed at any time without disturbing the motor.

With the assumption that all the heat generated in the coil ends flowed from the ends to the imbedded copper thence through the insulation, core, and frame, to the cooling water, a temperature gradient of 48 degrees C. between the end copper and the cooling water was calculated, using the overload losses of the motor and the usual thermal conductivity coefficients. Test results show that the gradient is actually considerably less than this, indicating that part of the heat went directly from the end windings to the frame. Thermocouples in various parts of the motor show that it is well within the temperature limits at all times, when supplied with about 30 gallons of cooling water per hour.

The rotor is only slightly different from the usual squirrel-cage type. The spider is a steel casting resembling a bushing more than a spider, as the shaft diameter is only two inches less than the inside diameter of the punchings. The laminations fit snugly on the spider and are held in place by a key and endplate. The winding is of the usual squirrel-cage type, with electrically brazed end rings. The upper end ring is provided with a number of lugs which are bolted to the spider. This serves to hold the winding in place. The lower end ring hangs free, allowing freedom for expansion and contraction due to temperature changes. The complete spider is pressed on the stabilizer shaft and is secured in place by a spanner nut.

The losses in the rotor must be dissipated principally by radiation and conduction through the shaft, and on this account they were made as low as possible. Tests on the stabilizer indicate that the rotor has never reached a high temperature.

When the spinning motor is to be a squirrel-cage induction motor, an individual source of power is required, the frequency of which can be varied at will during acceleration. On the Lyndonia this power is supplied by a turbine-generator set. The turbine is equipped with auxiliary nozzles for speed control. On another installation where the ship's drive is Diesel-electric, power is supplied by a motor-generator set. In this case the speed is varied by a combination of resistance and field control.



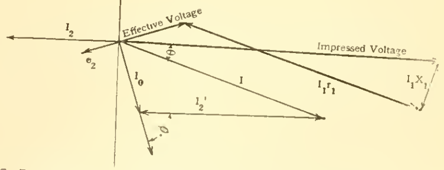


FIG. 7—DIAGRAM OF THE PRIMARY IMPEDANCE AT 50 CYCLES
FIG. 8—DIAGRAM OF THE PRIMARY IMPEDANCE AT ONE CYCLE

A rotary converter, operated inverted, may be used where direct-current power is available. This would be equally as good a source of power as an alternating-current generator or possibly better, if operated six-phase. In either case the peculiar requirements of this service must be considered in the design. When

starting the spinning motor the generator must run for a considerable time at reduced speed with a heavy overload current. Where self-ventilated machines are used, this means maximum heat to dissipate when the ventilation is poorest. The field and armature windings must be built to meet these conditions. The water cooled spinning motor is free from this difficulty. If the motor were to overheat during the accelerating period the supply of cooling water could be increased to correct the trouble.

In case of a rotary converter operating from a 125 volt direct-current ship circuit the highest alternating voltage will be 78 volts, three-phase or 90 volts, six-phase. With these voltages at full frequency the voltage at low frequency becomes very low. The brush contact resistance and the drop through the leads are quite important factors under these conditions and their effect on the performance of the set must be

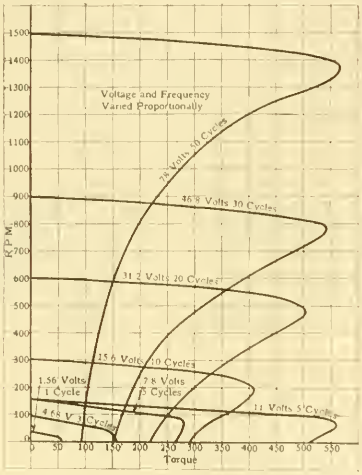


FIG. 9—SPEED TORQUE CURVES OF 35 HP SPINNING MOTOR

taken into account. If a rotary converter is to be used for this application, it should be operated six-phase to take advantage of the higher voltage ratio and reduced heating inherent to six-phase operation. Six-phase operation makes no difference in the performance of an induction motor.

The performance of the spinning motor at very low frequencies offers an interesting subject for analysis. It is commonly assumed that the torque of an induction motor can be kept constant for different frequencies by keeping the voltage and frequency proportional, thus maintaining a constant induction in the iron. This is practically true over a wide range of frequencies, in motors of normal design. For example, a 50 cycle, 500 volt motor having a maximum torque of 500 pounds would have a maxmium torque of about 490 lbs. when operated at 25 cycles, 250 volts. This slight difference is due to the primary resistance, which is constant, being a larger percentage of 250 volts than of 500 volts. This resistance drop is usually such a small percentage of the impressed voltage that in ordinary practice it may be neglected.

When motors are to be operated at extremely low frequencies this resistance drop becomes an increasingly large part of the primary impedance and must be considered. This may be readily seen by compar-

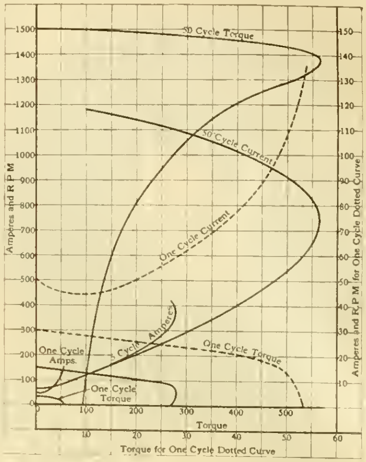


FIG. 10—TORQUE AND CURRENT CURVES OF SPINNING MOTOR AT 1, 5 AND 50 CYCLES

Voltage being proportional to frequency.

ing the vector diagrams of a motor at 50 cycles, Fig. 7 and the same motor at one cycle, Fig. 8. In Fig. 8 the scale for the voltage vectors has been multiplied by 50 to show the relative values of the different vectors more clearly. In the 50 cycle diagram the primary I_1R_1 drop vector is almost negligible. If this diagram were redrawn for 25 cycles, this vector would be just twice the length it is in the 50 cycle diagram and the effect would still be very small.

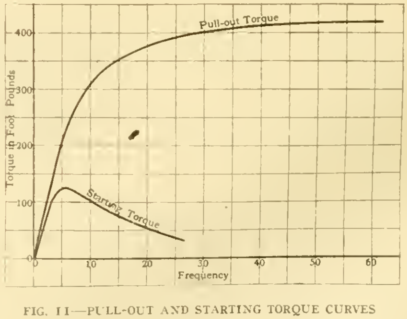


FIG. 11—PULL-OUT AND STARTING TORQUE CURVES

35 hp spinning motor driven by 31 kv-a alternating-current generator.

The primary reactance drop I_1X_1 which is normally five to ten times the resistance drop and consequently is the controlling factor in the impedance, is not affected in this manner by the change in frequency. The reactance, being directly proportional to the fre-

quency, varies with the voltage, the percent reactance remaining a constant. It will be noted in comparing Figs. 7 and 8, that the effective voltage for inducing power into the secondary is a much smaller part of the impressed voltage at one cycle than at 50 cycles, also that the power-factor, which is the cosine of the angle θ, is much better at one cycle than at 50.

The effect of the resistance drop on the maxmium torque can be seen in Fig. 9. The maximum torque decreases slowly between 50 and 10 cycles, then rapidly between 10 cycles and zero.

Another interesting change occurs in the characteristics of the motor with variable frequency. At 50 cycles the slip at full load and the starting torque are both small. The secondary resistance, being a constant, becomes an increasing percentage with decreasing frequency, and the percent slip and starting torque are increased.

This is a very important advantage of this method of starting squirrel-cage motors. Ordinarily the secondary resistance is made large enough to get the necessary starting torque with full frequency applied. When starting with very low frequency the motor can be so proportioned that the maximum torque will occur at starting and yet when it is up to full speed the characteristics will have changed so that the slip will be about half that of the usual motor, and the efficiency correspondingly higher. This is shown clearly in the speed torque curves of the same motor at 50 cycles and at one cycle, Fig. 10; here the one cycle curve is repeated in dotted lines to a larger scale for clearness. It will be noted that the maximum torques decrease to values even less than the full load torque at low frequencies. If it is necessary to have more torque at these very low frequencies the impressed voltage may be increased considerably without damage to the motor, as the core losses are small. Fig. 9 shows the curve at 5 cycles with the voltage increased to give the same torque obtained at 50 cycles.

In analyzing the performance at low frequencies it was found that with a particular spinning motor and its generator there was a very definite frequency where maximum starting torque could be obtained from the set. This frequency was approximately five cycles for the Lyndonia equipment. Above five cycles the starting torque begins to decrease due to the changing characteristics of the motor. Also the higher starting currents required by the motor at higher frequencies cause the generator voltage to be lowered. Fig. 11 shows the variation of pull out and starting torque of the set at different frequencies.

In cases where an individual generator is available this method of starting, and controlling the speed with variable frequency is very desirable. It is simple, flexible, and efficient. It gives practically constant torque over a wide range of speeds with very nearly constant current.

The Comparison of Small Capacities by a Beat Note Method

P. THOMAS
Westinghouse Research Laboratory

THE capacities of several pin type suspension insulators, and the capacities to ground of various numbers of the same insulators in series are exceedingly small. Rough measurements at low frequency by a bridge method show that they are of the order of 0.000025 microfarad. This value of capacity is about that of one millimeter on the scale of an ordinary variable air condenser, and it was desired that the results be accurate within five percent. It is apparent, then, that to reach this precision called for special methods, or apparatus, or both. No low frequency apparatus having sufficient sensitivity for this work was available. It was felt, also, that due to parallel leakage and absorption, results by any direct-current method would be open to considerable question.

A calculation showed that at a moderate radio frequency, the addition of one of these units in parallel with the oscillating circuit condenser, would alter the frequency by an amount corresponding to an audible tone, i.e. the ordinary "beat receiver", with suitable modifications, could be employed. The first idea tried was to tune two oscillating circuits to exact resonance, displace one of them by the addition of the unknown condenser, and restore synchronism by decreasing the capacity of the main oscillating condenser which had been paralleled by the unknown. The necessary decrease was found to be so small, however, as to require the calibration of special vernier air condensers.

It then occurred to us that something might be done by measuring the frequency of the beat note produced. This idea was worked out on paper, tried out roughly and finally adopted in the following form. Two oscillators were set up, one driven by a fifty watt transmitting tube, the other a standard regenerative detector-amplifier circuit with a loud speaking receiver. This receiver was found necessary, because of circuit capacity changes caused by use of head phones. In making a test, the two circuits were adjusted to give a beat note of a frequency suited to measurement by a second resonance with the note from an air siren, driven by a variable speed direct-current motor provided with a carefully calibrated tachometer. The unknown capacity was then added in parallel with the variable condenser in the detector circuit, thus caus-

ing a shift in the beat note frequency to a new value. The unknown capacity was then replaced by a small standard fixed condenser of accurately known capacity, and the frequency of this third beat note was measured in the same way. The unknown capacity could then be calculated from the known capacity and the three beat note frequencies, by direct ratio. The equations for the calculations were derived as follows:

The fundamental frequency is

$$F = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

The frequency with c added, is

$$F - f = \frac{1}{2\pi\sqrt{L(C+c)}} \qquad (2)$$

Squaring, eliminating C and cancelling common terms,

$$4\pi^2 Lc = \frac{2Ff+f^2}{F^3\left(F+2f+\frac{f^2}{F}\right)} \qquad (3a)$$

Neglecting terms involving f and f^2, as compared to F,

$$4\pi^2 Lc = \frac{2f}{F^3} \qquad (3b)$$

Or, expressing the fundamental wave in meters,

$$c = \frac{1.88 \times 10^{-27}\lambda^3 f}{L} \qquad (3)$$

A similar equation holds when the unknown capacity, c, is replaced by a second capacity c_0. Hence we have at once,

$$\frac{c}{c_0} = \frac{f}{f_0}$$

In these equations, the frequencies f and f_0 are the differences in beat note pitch between the beat note with neither c nor c_0 connected, and the pitch with (1) c and (2) c_0 connected. The quantity λ represents the fundamental wave length, in meters, of the primary oscillating circuit; this is supposed to remain constant, and when a substitution method is used, the value of λ does not enter the calculations. L is the inductance of the primary oscillating circuit.

In practical use of this method, two wavemeters are employed, one coupled to the primary oscillator, the other to the detector circuit. In this way it is made certain that the coupling between the two circuits is not close enough to introduce tuning waves of harmful strength. Fairly accurate measurements, in the absence of a fixed standard capacity, can be made by use of equation (3), since the primary inductance L is subject to exact calculation (single layer coil). The fundamental frequency F or wave length λ, however, is not exactly calculable by equation (1), so that for very exact work, the substitution method and equation (4) is more reliable. The method is beautifully simple and easy to operate, besides being extremely sensitive.

Table I gives the data and calculation for one test run on seven pin type suspension insulators, by the substitution method. The known condenser had a capacity of 0.0000828 microfarads. The circuits were tuned to a fundamental wave length of 1400 meters. The siren used had thirty holes, so that the r.p.m. as read on the tachometer was twice the frequency.

Note the value calculated by equation (3) for the standard, 0.0000790, as compared with its known value of 0.0000828. The values given in Table I, for

TABLE I—CAPACITY OF INDIVIDUAL INSULATORS.

Insulator Number	Beat Note On	Beat Note Off	Rdgs. Diff.	Calculated Capacity, mfds.
1	680	325	355	0.0000244
2	700	350	350	0.0000241
3	1085	740	345	0.0000237
4	1085	740	345	0.0000237
5	1090	715	375	0.0000258
6	1055	710	345	0.0000237
7	1020	675	345	0.0000237
Standard	1805	655	1150	0.0000790

the insulator capacities, were obtained by use of equation (4), taking the value for c_0 as 0.0000828.

Table II gives the capacities as determined for strings with various numbers in series; the theoretical series value, in the absence of distortion, is also given.

The departure from no-distortion values is shown strikingly by the values for six and seven string; the increase was due to the gradual approach of the lower end of the string to ground, as more insulators were added at the lower end. The upper insulator, No. 1, was kept at a constant height above ground, the string being lengthened at the lower end.

Considerable trouble was encountered with slow changes in frequency of the power circuit. The only satisfactory way to overcome this was found to be the use of closely similar tubes for both oscillator and detector circuits, with common plate voltage and filament current batteries. This shifting of the fundamental wave, when present in any degree, of course makes it difficult to get reliable readings; aside from this, however, no difficulties were encountered.

It can readily be seen that the limit of sensitivity of this method of capacity measurement has not by any means been reached in the work here described.

TABLE II—CAPACITIES OF VARIOUS NUMBERS OF INSULATORS IN A STRING

Insulators in String	Measured Capacity	Calculated Capacity No Distortion
1 & 2	0.0000158	0.0000121
1, 2 & 3	0.0000112	0.0000080
1, 2, 3 & 4	0.0000093	0.0000060
1, 2, 3, 4, & 5	0.0000072	0.0000049
1, 2, 3, 4, 5, & 6	0.0000082	0.0000040
1, 2, 3, 4, 5. 6, & 7	0.0000081	0.0000035

By the use of longer fundamental wave lengths, or larger oscillating condensers, or both, the differential tone may be kept around 500 to 1000 cycles when the unknown capacity is very much smaller than the values in these tests. The writer believes that it will be hard to find an alternating-current method of capacity measurement which will handle such small capacities, with such a high degree of accuracy and at the same time such marked ease of manipulation, as afforded by the method just described.

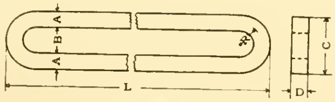
Methods of Magnetic Testing (Cont.)

THOMAS SPOONER

WHEN Dr. Burrows devised his permeameter (1909), it gave substantially correct results for all ferromagnetic materials then available. This method of test was therefore adopted by the A. S. T. M. a little later as the standard method for determining normal induction data. Since then, however, ferromagnetic materials have been developed with maximum permeabilities of several times those known in 1909.

ACCURACY

Some years ago, Mr. T. D. Yensen reported maximum permeability values of the order of 70 000 for special iron silicon alloys prepared in a vacuum[19]. These samples were in the form of rods and were tested by means of the Burrows permeameter. The maximum permeability values reported for ring samples prepared by him were about 40 000. Since then, we have found similar differences in material prepared at the Research Laboratory. Moreover, hysteresis loops at a maximum induction of ten kilogausses indicated that the Burrows apparatus gave results which were lower than those obtained by the ring test. These comparisons were not conclusive, however, as it is impossible to make two samples of different form having the same magnetic properties, at least when the magnetic quality is especially good. It was a very desirable, in order to evaluate data obtained with the Burrows apparatus to have some absolute method of checking the accuracy of this type of permeameter.



Dimensions in Cm.

	Silicon	Magnet		Silicon	Magnet
A	0.793	0.638	D	0.706	0.635
B	1.270	0.949	L	20.600	38.200
C	2.856	2.225	R	1.032	0.799

FIG. 10—STANDARD MAGNETIC LINK

The Fahy Simplex Permeameter, described previously, is used for tests on permanent magnet steel, due to the simplicity and reproducibility of results. We were therefore anxious to know its absolute accuracy, also, in order to compare our data with those obtained by other observers using other methods.

Check Methods—There are two simple, well known methods of determining the absolute magnetic characteristics of a ferro-magnetic material:—

1—A sample in the shape of an ellipsoid or a very long rod tested ballistically in a long solenoid or by means of a magnetometer.

2—Ring sample tested ballistically.

The first method has been used for checking permeameters by first preparing an ellipsoid, testing it and then machining it to a cylindrical bar and using it in the permeameter to be checked. This method has two disadvantages: first, an ellipsoid is a difficult shape to machine; and second, the further machining may introduce mechanical strains which may alter the character of the material. Even if the sample is subsequently annealed, it cannot be certain that the annealing has not altered the magnetic quality. In fact, it is probable that it would in most cases.

A more satisfactory method for checking permeameters is to use an elongated ring sample or link, Fig. 10, which may be tested either like a ring or as a bar. If such a sample is wound with a uniform magnetizing winding covering the whole length and is supplied with

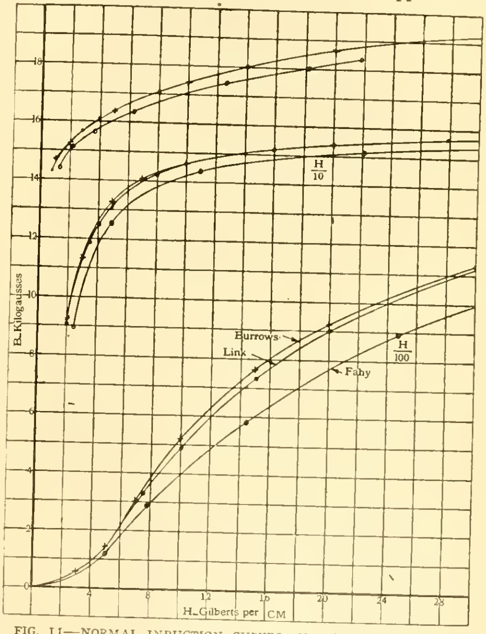


FIG. 11—NORMAL INDUCTION CURVES, SILICON STEEL LINKS, SAMPLE *A*

Test	μ Max
Ring	4960
Burrows	5240
Fahy	4060

a suitable secondary winding, it may be tested ballistically like a ring and the results should be correct except for a slight error at the ends, such as would be obtained with a ring sample in which the diameter is small with reference to the radial width. After testing as a ring, if the windings are removed the sample may then be placed in a permeameter and tested as a bar.

A number of such samples of varied magnetic qualities heve been prepared and tested in a Burrows permeameter and a Fahy simplex.

Test Samples—Tests are reported on link samples as shown in Table III with dimensions as given by Fig. 10.

TABLE III—TESTS ON LINK SAMPLES

Sample	Material	Max. μ
A	4% Silicon	4960
E	4% Silicon	10900
Z	4% Silicon	16700
G	4% Silicon	non-uniform
2027	Cr. mag.	164

The silicon steel samples were machined from standard sheet bars and heat treated by Mr. Yensen in an electric furnace. The magnet steel sample was machined from a standard chromium magnet steel bar and heated and quenched in the usual way before testing.

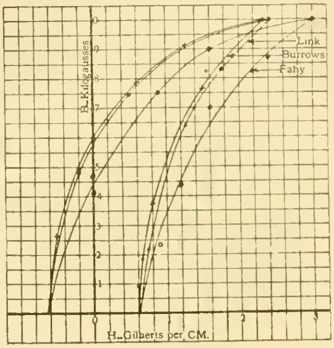


FIG. 12—HYSTERESIS LOOPS, SILICON STEEL LINK, SAMPLE *A*

For use in the Burrows apparatus a similar link of each kind was provided in order that the two legs of the apparatus might be approximately balanced.

It was noted in the earlier stages of the investigation that some of the higher permeability samples were not uniform magnetically. In order to test the uniformity, we therefore, wound exploring coils on

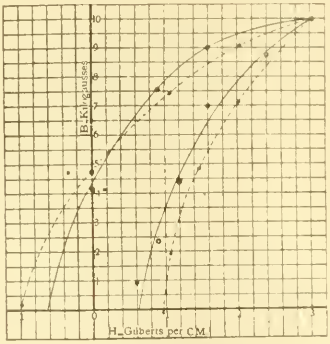


FIG. 13—COMPARISON OF FAHY TESTS, SILICON STEEL LINK, SAMPLE *A*

various portions of the links and tested ballistically to see if the various coils when connected differentially gave appreciable deflections. All samples reported here, except the *G* sample, were found to be practically uniform. The lack of uniformity of the earlier samples was found to be due to the fact that the heat treating furnace was not uniform in temperature throughout its length. This was corrected in treating the later samples.

Permeameters—The ring tests were made by means of the apparatus previously described[15]. The Burrows permeameter was designed and built by the Westinghouse Company and was arranged for use with sheet and bar material. By reference to Fig. 9, it will be seen that the flux passes into and out of the sheets or bars through the edges of the sample. This magnetic circuit was especially well adapted for use with the link samples. It will be noted that the yokes

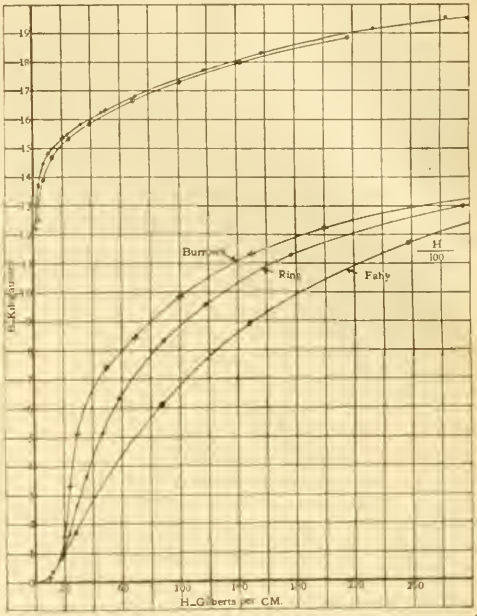


FIG. 14—NORMAL INDUCTION CURVES, SILICON STEEL LINK SAMPLE *E*

Test	μ Max
Ring	10900
Burrows	17500
Fahy	7310

are laminated and made of high-permeability, low-hysteresis-loss material, thus reducing magnetic viscosity effects and effects due to the retentivity of the yokes. The Fahy permeameter was of the simplex type. In most cases the operation was according to the method given in the instructions which accompanied the apparatus.

Test Results—Figs. 11 to 20 show the test data obtained on these link samples. For all three methods of test each point on the hysteresis loops was obtained independently of the others by reference to the tip value. ΔB was measured by introducing resistance into the magnetic circuit with or without reversing the magnetizing current and B was found by subtracting

ΔB from the tip value. For the ring and Burrows apparatus, H was measured by suitable accurately calibrated ammeters.

For the Fahy permeater, two methods were used in obtaining H. The standard method consists in measuring H by means of the galvanometer deflection when the resistance in the magnetizing circuit is increased to infinity. This assumes that there is no residual magnetism in the yokes. We also tried the method of measuring ΔH when the magnetizing current was reduced from the maximum value and subtracting this ΔH from the tip value. A comparison of these two methods is given by Fig. 13, where the full line loop is reproduced from Fig. 12 and represents the data as obtained by the standard method. The two values of B_r as shown by the circles were read, depending on whether zero H was obtained by reducing the magnetizing current to zero in two steps or in one, the lower value of B being obtained when using the former method. It will be noted that the

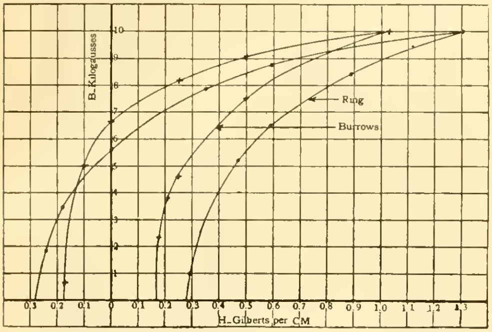


FIG. 15—HYSTERESIS LOOPS, SILICON STEEL LINK, SAMPLE *E*

corresponding dots, Fig. 13, represent the same points when ΔH is measured from the tip.

The data of Fig. 20 were obtained on a very non-uniform link, the material having high permeability at the center and low at the ends. Primary and secondary coils were arranged as shown by the sketches. Coils *2* and *3* had half the number of turns of coils *1*. Coils *2* were spaced about half way between the center and ends of the sample. The primary coils were uniformly wound, the magnetizing coils P occupying about 20 cm. length of the sample and the compensating coils C about 10 cm. on each end. There was also a uniform secondary winding not shown, extending the whole length of the sample. These windings were connected to a Burrows permeameter table and a Burrows test made in the usual way, using first, coils *1* and *2*, then coils *1* and *3*. Since coils *3* together had only one-half the turns of coils *1* together, coils *3* in series were bucked against one of the coils *1* for the compensating adjustment. This should introduce no error, however, since both sides of the links were identical at the center. It will be noted that this arrangement is the equivalent of a Burrows permeater in which the yokes are a part of the material.

A Burrows test with the regular Burrows yoke was also made on this sample and likewise a ring test using the distributed secondary winding.

RESULTS

Fig. 11 for the 5000-maximum permeability material shows a very fair agreement between the ring and Burrows tests, with the Burrows slightly low in H at moderate inductions and checking at the higher values. The Fahy shows a nearly constant percentage of error in H at all inductions, the H values being about ten percent high. The hysteresis losses (at $B_{max}=10$ kilogausses) for the various methods of test as shown by Fig. 12 are about the same but the Fahy gives a low value of B_r. As shown by Fig. 13 for the Fahy results

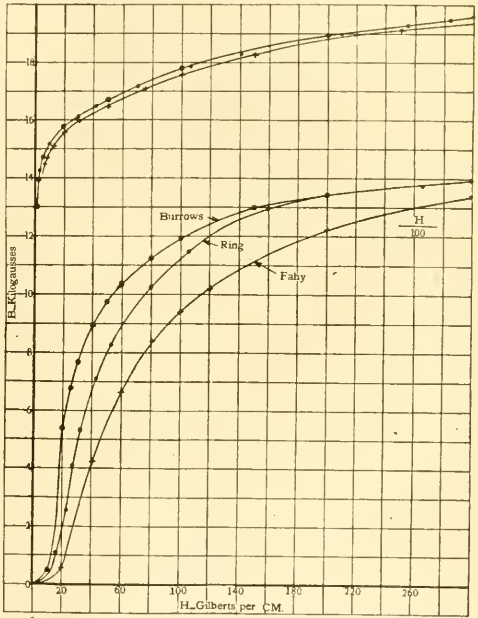


FIG. 16—NORMAL INDUCTION CURVES, SILICON STEEL LINK SAMPLE Z

Test	μ Max
Ring	16700
Burrows	28200
Fahy	11000

the standard method as recommended by the manufacturer gives better results for the hysteresis loop than method 2. The Fahy simplex in its present form is not suitable for obtaining hysteresis data on high-maximum permeability, low-loss material, since the H readings are too small to read accurately and the results are erratic. It should be noted that the circle points of Fig. 13 do not give a smooth curve. It was impossible to obtain any kind of reasonable hysteresis data for the 11 000 maximum permeability material with the Fahy simplex.

Fig. 14 for the 11 000-maximum-permeability material shows the same effects as for the 5000 permeability material, except that the differences are exaggerated. The maximum permeability for the Burrows

apparatus is 60 percent high and for the Fahy 33 percent low. At inductions above 14 kilogausses, the Burrows and ring tests check, with the Fahy running slightly high in H.

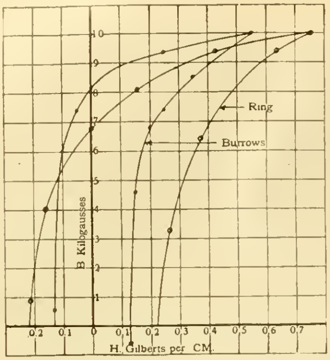


FIG. 17—HYSTERESIS LOOPS, SILICON STEEL LINK, SAMPLE Z

There is a considerable error for all constants of the hysteresis loop (see Fig. 15) between the Burrows and ring tests. The Burrows give a high B_r, low H_c and low hysteresis loss, which is in line with our expectations from previous data.

The permanent magnetic steel sample (Fig. 18) gives very good checks at all inductions, with the Fahy running slightly low in B at high inductions. The hysteresis constants (Fig. 19) are practically identical for the ring and Burrows test, both for loops having

FIG. 18—NORMAL INDUCTION CURVES, CHROMIUM MAGNET STEEL LINK, SAMPLE 2027.

H_{max} of 50 and 100. The Fahy gives slightly low values of B_r and H_c.

The tests on the non-uniform sample (Fig. 20) are very interesting. For the ring test results, the values of H are considerably too high for the center of the sample and too low for the ends. All the other tests probably give values of H which are too low even for the center of the sample. It is apparent that if the permeability at the location of coils *2*, is less than at the center, (the location of coils *1*) more current will have to be passed through the compensating coils C in order to give the same flux through coils *1* and *2* than would be the case if the material were uniform. That these fluxes must be equal is the condition of balance for the Burrows test. It is obvious that if the sample is sufficiently non-uniform and the exploring coils are wound close to the sample, a condition would be reached where an apparent permeability of infinity would be indicated. In fact, we have nearly reached this condition in this case, where we have an observed maximum permeability of 125 000 where the material probably has a maximum permeability at the center of about 15 000. The uniformity tester devised by the Bureau of Standards[20] will probably not show definitely a gradual change of permeability from the center

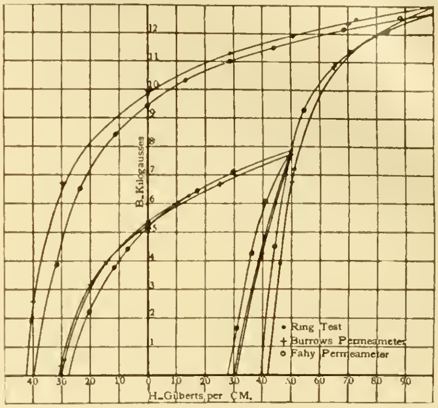


FIG. 19—HYSTERESIS LOOPS, CHROMIUM MAGNET STEEL LINK, SAMPLE 2027.

to the ends, as the effect would be confused with the ordinary leakage effects. The only remedy is to insure that the samples have received uniform heat treatment and are of uniform material to start with.

There is a correction which may be applied to the Burrows data due to the magnetizing effect of the compensating coils. This correction was not applied to these data, but approximate calculations were made in two or three cases and it was found that this effect would account for only a small percent of the difference between the ring and Burrows H values.

CONCLUSIONS

The following conclusions apply to the Fahy simplex permeameter as at present constructed and to the Burrows permeater having a magnetic circuit of the dimensions shown in Fig. 9.

1—A simple and accurate method is described for checking the absolute accuracy of permeameters taking rectangular bar samples.

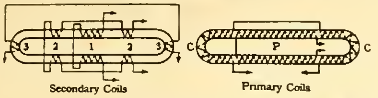
2—The limitations and accuracy of the Burrows and Fahy Simplex permeameters are shown for certain specific samples.

3—These permeameters will give fairly accurate normal induction results for any ferro-magnetic material at high inductions.

4—At lower inductions the Burrows normal induction H values begin to be too low for material having a maximum permeability of over 5000. The Fahy permeameter gives too large values of H at moderate inductions for any material except very low maximum permeability samples, such as permanent magnetic steel. The error gets larger as the maximum permeability increases.

5—For material having a maximum permeability of 5000 or less, the Burrows permeameter gives practically correct results for ten kilogauss hysteresis loops. As the maximum permeability increases above this figure, the observed B_r becomes too large and H_c and the hysteresis loss, too small. In general, the Fahy permeameter apparently gives values of B_r and H_c which are slightly low for all materials. In its present form it is not suitable for hysteresis tests on high permeability material due to the fact that the H coil is too insensitive and due to erratic results.

6—In using the Burrows permeameter, great pains must be taken to insure that the samples are uniform in magnetic properties along their length, as otherwise very large errors may be introduced.



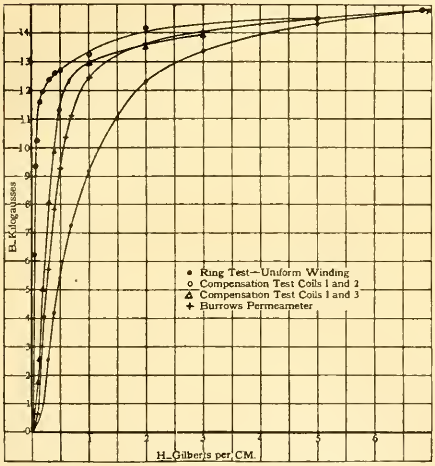


FIG. 20—NORMAL INDUCTION CURVES, NON-UNIFORM SILICON LINK, SAMPLE *G*

7—The Fahy simplex permeameter should in general be used (at least in its present form) only for magnetically hard material. Although the results are not quite correct with the apparatus, they are very reproducable. The Fahy, due to the simplicity of operation, is especially suitable for determining the effect of small changes of heat treatment on magnetic properties.

8—Where accurate results are required on high maximum permeability material, a ring sample should be used.

Rod Samples—In order to check the accuracy of the Burrows permeameter for rod samples, a special one-half inch outside diameter rod was drilled through its entire length with a 9/32 in. hole. An exploring coil about four inches long was then wound on a 1/8 inch diameter glass tube, consisting of about 23 000 turns of very fine enamelled wire. This coil was calibrated by placing it in a long solenoid, reversing the primary solenoid current and noting the deflection of a calibrated fluxmeter connected to the exploring coil. This exploring coil was then placed inside of the hollow bar and the whole inserted in a Burrows permeater. H was then read for various values of B, both by means of the exporing coil in the bar and by the usual method. The results are given in Table IV.

The first two points are not very reliable due to the small readings on the H coil. If a sufficiently sensitive galvanometer were available, such a test as this would yield very satisfactory check values for lower inductions where the departure from true values may be greatest with the Burrows apparatus.

RECOMMENDATIONS

For routine commercial tests on permanent magnet steel in bar form, several of the available commercial permeameters are satisfactory. For very rapid work, where comparative results only are desired, the Koepsel type of apparatus is perhaps as satisfactory as any. Where results in absolute units are required the Fahy simplex permeameter is simple and reasonably accurate, if a small correction is applied to B_m and H_c. For research work, where samples are to be standardized, or for other reasons where absolute accuracy is required, the Burrows permeameter is the most satisfactory apparatus available and may be relied on to a

TABLE IV—COMPARATIVE ROD TESTS

B	H Burrows	H Coil	Percent Difference
11.50	2.	1.95	+2.5
13.59	5.	4.81	+4.
14.68	10.	10.15	—1.5
15.21	20.	20.4	—2.0
16.11	50.	50.3	—0.6
17.27	100.	100.8	—0.8

fraction of one percent. An exception to this statemenet will have to be made, however, in the case of the new Honda steels. Most, if not all of the commercial permeameters on the market can not be operated at the high magnetizing forces necessary for this material, without serious overheating.

For routine tests on electrical sheet material the Fahy simplex apparatus may be used if results to 10 or 15 percent absolute accuracy only are required. The Burrows apparatus in its simplified form arranged for the A. S. T. M. test is probably the most satisfactory apparatus available if absolute accuracy of results is required, coupled with fair speed of test, using Epstein strips. Some of the other permeameters may be used with suitable correction curves, but the results are more or less open to question.

For research work, except for permanent magnet steel, where samples are to be prepared from experimental ingots or when dealing with material having maximum permeabilities of over 5000 or 6000 we believe it advisable to use the ring form of sample, due to the simplicity of the test, the ease of forming samples and the absolute accuracy which may be attained.

[19]"Magnetic and Other Properties of Iron Silicon Alloys Melted in Vacuo" by T. D. Yensen, *University of Illinois Bulletin No. 83, Eng. Experimental Station.*

[20]*Bulletin of Bureau of Standards,* Vol. XIV, No. 1, April 6, 1918.

(*To be continued*)

Transmission Line and Transformers

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THE methods usually employed to include the effects of transformers on transmission systems consist of separate calculations for the line and for the transformers. In a previous article* the authors recommended the use of general circuit constants, which include the tranfsormers as well as the transmission line itself. In that article the effect of transformer exciting kv-a was neglected, though the effect of transformer impedance was included. It is the object of the present article to investigate different methods of including transformers and to indicate the desirable approximations and the magnitude of errors involved in these approximations.

A transformer may be accurately represented by the network shown in Fig. 1. In this diagram T_r represents a transformer impedance and Y_r represents transformer shunt admittance. T_r and Y_r are complex quantities whose real parts represent the copper loss and iron loss and whose imaginary parts represent transformer reactive kv-a and magnetizing kv-a respectively. Another method which is sometimes employed to represent a transformer is shown in Fig. 2.

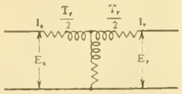

FIG. 1—NETWORK ACCURATELY REPRESENTING A TRANSFORMER

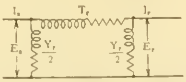

FIG. 2—APPROXIMATE NETWORK FOR A TRANSFORMER

The use of the network as shown in Fig. 1 is usually limited to the development of formulas and to those cases where the voltage varies the exciting kv-a and where the exciting kv-a is of considerable importance. An example of such a case is the problem of determining the rise in voltage in a transmission line when the generator becomes self-exciting. As the transformer exciting kv-a increases very rapidly with increase in voltage, it becomes an important factor in limiting the voltage rise. The solution is obtained by the cut and try method, using the constants of the transmission circuit in conjunction with the voltage-exciting current curve of the transformer. The network shown in Fig. 2 is rather generally employed for determining voltage regulation in transmission systems involving transformers when the calculations are made for each part separately. This network, however, introduces a small error.

The general circuit constants for the networks which are used to represent transformers are listed in Table I. By employing these circuit constants the relation between generator and receiver (primary and secondary) voltages and currents may be simply stated as follows**:—

$$E_s = A_0 E_r + B_0 I_r \qquad (1)$$

$$I_s = C_0 E_r + D_0 I_r \qquad (2)$$

It will be noted that the A_o and D_o constants for the two networks are identical but that the B_o and C_o constants for the network shown in Fig. 2 are incorrect. For the usual cases the transformer impedance will not exceed ten percent and the exciting kv-a also will not exceed ten percent. Hence the error in the B_o and C_o constants will usually be less than one fourth of one percent. On this account it is usually permissible to employ the network shown in Fig. 2 instead of the one shown in Fig. 1 and is generally desirable for numerical solution by parts.

The next step is to consider the general case of a transmission line with transformers at either end, the transformers being represented by their equivalent network as shown in Fig. 3. The circuit constants for the individual network comprising receiver transformer, transmission line and supply transformer are listed in Table II. From these constants the general

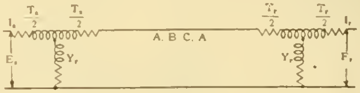

FIG. 3—NETWORK FOR A TRANSMISSION LINE, INCLUDING THE SUPPLY AND RECEIVER TRANSFORMERS

circuit constants A_o, B_o, C_o and D_o may be obtained by substitution in equations (1) to (4) of page 306 of the JOURNAL for July 1921. The value of these general circuit constants are as given under item (t) in Table III. These equations give the exact expressions for the general circuit constants for a transmission system including transformers at both supply and receiver ends.

The formulas just developed appear quite complicated and the next step is to simplify them for practical calculations. It has already been pointed out that in general the quantities $1 + \frac{T_s Y_s}{4}$ and $1 + \frac{T_r Y_r}{4}$ may be replaced by unity without the error exceeding

*In the JOURNAL for July 1921, p. 306.

**The application of these constants may be explained as follows:— In a circuit of constant impedance characteristics the supply voltage in general varies with receiver voltage and receiver current. Hence we may write equation (1) with A_0 and B_0 as proportionality constants. Similarly the current at the supply in general varies with receiver current and with receiver voltage. Hence we may also write equation (2) with C_0 and D_0 as proportionality constants. A_0 is the ratio of supply to receiver voltage under open circuit, B_0 is the equivalent impedance, C_0 is the equivalent shunt admittance, and D_0 is the ratio of supply to receiver currents with short circuited receiver.

¼ percent. Similarly $1+\frac{T_s Y_s}{2}$ and $1+\frac{T_r Y_r}{2}$ may also be replaced by unity without the error exceeding ½ percent. By employing these devices, general circuit constants for the case shown in Fig. 3 may be written as given under item (w) in Table III and will be accurate within one percent.

Many schemes have been proposed to produce a simple but sufficiently exact method of including transformers at each end of the transmission line. To show the relative simplicity and accuracy of several of these schemes and also to show the characteristics of general circuit constants for different types of networks, Table III has been prepared. All the formulas given in Table III are exact for the networks shown, unless otherwise indicated.* The accuracy of the approximate methods is based on transformers having ten percent exciting kv-a and ten percent impedance. For the cases where exciting kv-a and impedance are lower than ten percent the amount of the error will be reduced accordingly: e.g., with five percent exciting kv-a and five percent impedance the error will be reduced to ¼ of that indicated in Table III. Perhaps it should be pointed out that the product $T_r\ Y_r$ for a transformer in ohms and mhos is equal to the product of T_r and Y_r expressed as a complex number with decimals corresponding to the percent impedance and percent exciting kv-a.

TABLE I.—CIRCUIT CONSTANTS FOR TRANSFORMER NETWORKS.

Circuit Constants	Fig. 1	Fig. 2
A_0	$\left(1+\frac{T_r Y_r}{2}\right)$	$\left(1+\frac{T_r Y_r}{2}\right)$
B_0	$T_r\left(1+\frac{T_r Y_r}{4}\right)$	T_r
C_0	Y_r	$Y_r\left(1+\frac{T_r Y_r}{4}\right)$
D_0	$\left(1+\frac{T_r Y_r}{2}\right)$	$\left(1+\frac{T_r Y_r}{2}\right)$

In connection with the various schemes given in Table III to represent transformers, it is to be noted that on setting the exciting admittances equal to zero, all the formulas for each condition reduce to the same expression. In other words the several formulas given for each of the different conditions differ only in terms which involve exciting admittance. On this account the use of various approximate formulas is recommended in preference to the use of the exact solutions, because the shunt admittance of a transformer is not known with any high degree of exactness and in general the shunt admittance will vary somewhat with the different load conditions.

Occasionally it has been proposed to add transformer series impedance directly to the transmission line impedance and the transformer shunt admittance directly to the transmission line shunt admittance and to use these new values for obtaining the circuit constants for the transmission system. This method is not to be recommended because it does not have a mathematical basis, and because it is not as convenient to employ as the approximate solution given in Table III, particularly in case the general circuit constants are required for two or more transformer combinations at either the supply or receiver end.

It has also been proposed to add transformer series impedance to the B constant of the transmission line to obtain the B_0 constant and to add the transformer shunt admittance to the C constant to obtain the C_0 constant. This is a very approximate method and may give rise to an error much greater than one percent, as may be readily shown from the circuit constants for a particular case e.g., item (t) in Table III. This method is not to be recommended because of its inaccuracy.

TABLE II.—CIRCUIT CONSTANTS FOR FIG. 3.

$A_1=1+\frac{T_r Y_r}{2}$	$A_2=A$	$A_3=1+\frac{T_s Y_s}{2}$
$B_1=T_r\left(1+\frac{T_r Y_r}{2}\right)$	$B_2=B$	$B_3=T_s\left(1+\frac{T_s Y_s}{4}\right)$
$C_1=Y_r$	$C_2=C$	$C_3=Y_s$
$D_1=1+\frac{T_r Y_r}{2}$	$D_2=A$	$D_3=1+\frac{T_s Y_s}{2}$

A study of Table III shows that for the problems involving transmission lines and transformers, two general methods of solution may be employed. Conditions given in items (n), (r) and (v) may be solved by including the exciting admittances as part of the transmission system or as part of the load on the system. If the exciting admittance is considered as part of the transmission system, the solution is given under items (n), (r) and (v). If the exciting admittance is considered as part of the load on the system, the receiver transformer exciting kv-a is added to the receiver load and the supply transformer exciting kv-a is treated as a separate load on the supply and the circuit constants given in Table III under items (i), (j) and (k) will be employed. Between these two methods there is little choice, though the method of considering exciting kv-a as part of the load on the system has some advantage in that the circuit constant formulas are simpler and the method slightly more accurate, and that changes in exciting kv-a with changes in voltage are more readily taken into account, while the other method gives a complete solution and

*This statement is based on representing transformers by the net-work shown in Fig. 1, in which the primary and secondary self impedances, when expressed in terms of the same voltage, are assumed equal. These impedances may be unequal but sufficient data is usually not available to determine their value and on this account it is customary to assume the impedances equal. The error introduced into the transmission constant by this assumption is exceedingly small.

TABLE III.—CIRCUIT CONSTANTS FOR DIFFERENT NETWORKS

Item	Type of Network	Circuit Constants A_0	B_0	C_0	D_0	Comments
(a)	E_s T_r E_r Series Impedance	1	T_r	0	1	
(b)	E_s Y_r E_r Shunt Admittance	1	0	Y_r	1	
(c)	E_s $T_r/2$ Y_r $T_r/2$ E_r Transformer	$1+\frac{T_rY_r}{2}$	$T_r\left(1+\frac{T_rY_r}{4}\right)$	Y_r	$1+\frac{T_rY_r}{2}$	Transformer, Exact
(d)	E_s $\frac{Y_r}{2}$ T_r $\frac{Y_r}{2}$ E_r	$1+\frac{T_rY_r}{2}$	T_r	$Y_r\left(1+\frac{T_rY_r}{4}\right)$	$1+\frac{T_rY_r}{2}$	Transformer, Approximate Error 0.25%
(e)	E_s T_r Y_r E_r	$1+T_rY_r$	T_r	Y_r	1	Transformer, Approximate Error 0.5
(f)	E_s Y_r T_r E_r	1	T_r	Y_r	$1+T_rY_r$	Transformer, Approximate Error 0.5
(g)	Transformer Approximate Network	1	T_r	Y_r	1	Transformer, Approximate Error 0.5
(h)	E_s A, B, C, A E_r Transmission Line (T.L.)	$\overset{*}{A}=\cosh\sqrt{ZY}$	$\overset{*}{B}=\sqrt{\frac{Z}{Y}}\sinh\sqrt{ZY}$	$\overset{*}{C}=\sqrt{\frac{Y}{Z}}\sinh\sqrt{ZY}$	$\overset{*}{A}=\cosh\sqrt{ZY}$	Transmission Line, Exact
(i)	E_s A, B, C, A T_r E_r T. L. and Series Impedance at Receiver	A	$B+AT_r$	C	$A+CT_r$	Exact
(j)	E_s T_s A, B, C, A E_r T. L. and Series Impedance at Supply	$A+CT_s$	$B+AT_s$	C	A	Exact
(k)	E_s A, B, C, A E_r T. L. and Series Impedance at Both Receiver and Supply	$A+CT_s$	$B+A(T_r+T_s)+CT_rT_s$	C	$A+CT_r$	Exact
(l)	E_s A, B, C, A E_r Items (c) Plus (h)	$A\left(1+\frac{T_rY_r}{2}\right)+BY_r$	$B\left(1+\frac{T_rY_r}{2}\right)+AT_r\left(1+\frac{T_rY_r}{4}\right)$	$C\left(1+\frac{T_rY_r}{2}\right)+AY_r$	$A\left(1+\frac{T_rY_r}{2}\right)+CT_r\left(1+\frac{T_rY_r}{4}\right)$	Transmission Line and Receiver Transformer, Exact
(m)	E_s A, B, C, A E_r Items (d) Plus (h)	$A\left(1+\frac{T_rY_r}{2}\right)+BY_r\left(1+\frac{T_rY_r}{4}\right)$	$B\left(1+\frac{T_rY_r}{2}\right)+AT_r$	$C\left(1+\frac{T_rY_r}{2}\right)+AY_r\left(1+\frac{T_rY_r}{4}\right)$	$A\left(1+\frac{T_rY_r}{2}\right)+CT_r$	Transmission Line and Receiver Transformer, Approximate Error 0.25%
(n)	E_s A, B, C, A E_r Items (e) Plus (h)	$A(1+T_rY_r)+BY_r$	$B+AT_r$	$C(1+T_rY_r)+AY_r$	$A+CT_r$	Transmission Line and Receiver Transformer, Approximate Error 0.5
(o)	Transmission Line and Receiver Transformer Approximate Network Error .5%	$A+BY_r$	$B+AT_r$	$C+AY_r$	$A+CT_r$	Transmission Line and Receiver Transformer, Approximate Error 0.5
(p)	E_s A, B, C, A E_r Items (h) Plus (c)	$A\left(1+\frac{T_sY_s}{2}\right)+CT_s\left(1+\frac{T_sY_s}{4}\right)$	$B\left(1+\frac{T_sY_s}{2}\right)+AT_s\left(1+\frac{T_sY_s}{4}\right)$	$C\left(1+\frac{T_sY_s}{2}\right)+AY_s$	$A\left(1+\frac{T_sY_s}{2}\right)+BY_s$	Transmission Line and Supply Transformer, Exact
(q)	E_s A, B, C, A E_r Items (h) Plus (d)	$A\left(1+\frac{T_sY_s}{2}\right)+CT_s$	$B\left(1+\frac{T_sY_s}{2}\right)+AT_s$	$C\left(1+\frac{T_sY_s}{2}\right)+AY_s\left(1+\frac{T_sY_s}{4}\right)$	$A\left(1+\frac{T_sY_s}{2}\right)+BY_s\left(1+\frac{T_sY_s}{4}\right)$	Transmission Line and Supply Transformer, Approximate Error 0.25%
(r)	E_s A, B, C, A E_r Items (h) Plus (f)	$A+CT_s$	$B+AT_s$	$C(1+T_sY_s)+AY_s$	$A(1+T_sY_s)+BY_s$	Transmission Line and Supply Transformer, Approximate Error 0.5%
(s)	Transmission Line and Supply Transformer, Approximate Error 0.5%	$A+CT_s$	$B+AT_s$	$C+AY_s$	$A+BY_s$	Transmission Line and Supply Transformer, Approximate Error 0.5%
(t)	E_s A B C A E_r Transmission Line and Both Transformers	$A_0=A\left[\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{2}\right)+T_sY_r\left(1+\frac{T_sY_s}{4}\right)\right]+BY_r\left(1+\frac{T_sY_s}{2}\right)+CT_s\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{4}\right)$ $B_0=B\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{2}\right)+A\left[T_r\left(1+\frac{T_rY_r}{4}\right)\left(1+\frac{T_sY_s}{2}\right)+T_s\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{4}\right)\right]+CT_rT_s\left(1+\frac{T_rY_r}{4}\right)\left(1+\frac{T_sY_s}{4}\right)$ $C_0=C\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{2}\right)+A\left[Y_r\left(1+\frac{T_sY_s}{2}\right)+Y_s\left(1+\frac{T_rY_r}{2}\right)\right]+BY_rY_s$ $D_0=A\left[\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{2}\right)+T_rY_s\left(1+\frac{T_rY_r}{4}\right)\right]+BY_s\left(1+\frac{T_rY_r}{2}\right)+CT_r\left(1+\frac{T_rY_r}{4}\right)\left(1+\frac{T_sY_s}{2}\right)$				Transmission Line and Supply and Receiver Transformer, Exact
(u)	E_s A B C A E_r	$A_0=A\left[\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{2}\right)+T_sY_r\left(1+\frac{T_rY_r}{4}\right)\right]+BY_r\left(1+\frac{T_rY_r}{4}\right)\left(1+\frac{T_sY_s}{2}\right)+CT_s\left(1+\frac{T_rY_r}{2}\right)$ $B_0=B\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{2}\right)+A\left[T_s\left(1+\frac{T_rY_r}{2}\right)+T_r\left(1+\frac{T_sY_s}{2}\right)\right]+CT_rT_s$ $C_0=C\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{2}\right)+A\left[Y_r\left(1+\frac{T_rY_r}{4}\right)\left(1+\frac{T_sY_s}{2}\right)+Y_s\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{4}\right)\right]+BY_rY_s\left(1+\frac{T_rY_r}{4}\right)\left(1+\frac{T_sY_s}{4}\right)$ $D_0=A\left[\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{2}\right)+T_rY_s\left(1+\frac{T_sY_s}{4}\right)\right]+BY_s\left(1+\frac{T_rY_r}{2}\right)\left(1+\frac{T_sY_s}{4}\right)+CT_r\left(1+\frac{T_sY_s}{2}\right)$				Transmission Line and Supply and Receiver Transformer Approximate Error 0.25%
(v)	E_s A, B, C, A E_r	$A_0=A\left[(1+T_rY_r)+Y_sT_r\right]+BY_r+CT_s(1+T_rY_r)$ $B_0=B+A(T_r+T_s)+CT_rT_s$ $C_0=C(1+T_rY_r)(1+T_sY_s)+A\left[Y_r(1+T_sY_s)+Y_s(1+T_rY_r)\right]+BY_rY_s$ $D_0=A\left[(1+T_sY_s)+Y_sT_r\right]+BY_s+CT_r(1+T_sY_s)$				Transmission Line, Supply and Receiver Transformer Approximate Error 0.5%
(w)	Transmission Line, Supply and Receiver Transformer Approximate Network	$A_0=A+CT_s+Y_r(AT_s+B)$ $B_0=B+A(T_r+T_s)+CT_rT_s$ $C_0=C+BY_rY_s+A(Y_r+Y_s)$ $D_0=A+CT_r+Y_s(B+AT_r)$				Transmission Line, Supply and Receiver Transformer Approximate Error 1%
(x)	E_s T_s A_2 B_2 C_2 A_2 T_m A_1 B_1 C_1 A_1 T_r E_r Two T. L. and Three Trans. Solution is approximate. Item (g) Represents Middle Trans.	$A_0=(A_2+C_2T_s)(A_1+C_1T_m)+(B_2+A_2T_s)(A_1Y_m+C_1)$ $B_0=(A_2+C_2T_s)(B_1+A_1T_r+A_1T_m+C_1T_mT_r)+(B_2+A_2T_s)(A_1+C_1T_r+Y_mB_1+Y_mA_1T_r)$ $C_0=C_2(A_1+C_1T_m)+A_2(A_1Y_m+C_1)$ $D_0=(A_1+C_1T_r)(A_2+C_2T_m)+(B_1+A_1T_r)(A_2Y_m+C_2)$				Two Transmission Lines in Series and Three Transformers, Approximate Error 1% Note Receiver and Supply Transformer Exciting Kv-a Considered as Part of the Loads
(y)	Transmission Systems In Parallel	$A_0=\frac{A_1B_2+A_2B_1}{B_1+B_2}$	$B_0=\frac{B_1B_2}{B_1+B_2}$	$C_0=C_1+C_2+\frac{(A_1-A_2)(D_2-D_1)}{B_1+B_2}$	$D_0=\frac{B_1D_2+B_2D_1}{B_1+B_3}$	Two Transmission Systems In Parallel, Exact

$E_s=A_0E_r+B_0I_r$ $\quad E_r=D_0E_s-B_0I_s$ $\quad {}^*A=\left(1+\frac{ZY}{1\cdot2}+\frac{Z^2Y^2}{1\cdot2\cdot3\cdot4}\cdots\right)$ $\quad {}^*B=Z\left(1+\frac{ZY}{2\cdot3}+\frac{Z^2Y^2}{2\cdot3\cdot4\cdot5}\cdots\right)$ $\quad {}^*C=Y\left(1+\frac{ZY}{2\cdot3}+\frac{Z^2Y^2}{2\cdot3\cdot4\cdot5}\cdots\right)$

$I_s=C_0E_r+D_0I_r$ $\quad I_r=-C_0E_s+A_0I_s$

Z = Impedance Per Mile × Miles
Y = Admittance Per Mile × Miles

does not require a correction for each load condition.

The case of two transmission lines in series connected through a transformer or an auto-transformer is given under item (x). Here the solution is obtained by employing the circuit given under item (x) and by considering the exciting kv-a of the receiver transformers as part of the receiver load and the exciting kv-a of the supply transformer as a separate load on the supply. This case is a good example to show the possibilities of obtaining relatively simple expressions for circuit constants for complex networks by employing suitable combinations of approximate formulas given in Table III. Item (y) really covers the general case of two networks in parallel. The relation that the two transmission systems have the same terminal voltages is sufficient to determine the equivalent constants covering both lines. For each of these cases, items (x) and (y), the voltage of the two transmission systems may be different, and it becomes necessary to express the constants of both systems in terms of the same voltage before the general circuit constants for the systems as a whole can be determined. For this purpose the constants A and D will be the same for any voltage, the B constant will be changed inversely as the square of the ratio of the two voltages and the C constant directly as the square of the ratio of the voltages.

TABLE IV—METHOD OF CALCULATING CIRCUIT CONSTANTS

Condition	Item Numbers in Table III	
	Exact Solution	Approximate Solutions
Transmission line and receiver transformer	l	r or l *
Transmission line and supply transformer	p	s or j *
Transmission line and both receiver and supply transformers	t	o or k *

*These methods require that the transformer exciting kv-a be considered as part of the load. With the other methods transformer exciting kv-a is considered as part of the transmission system.

SUMMARY

It is now possible to indicate the best methods of taking transformers into account in transmission problems. Where the highest degree of accuracy is required the exact solution should be employed but for the usual case approximate solutions are adequate. Table IV indicates the most useful solutions, which are given in Table III.

CONCLUSION

The use of general circuit constants applicable to the transmission system as a whole is recommended. The use of these constants simplifies the calculation for even one load condition, and also provides the constants in the form most convenient for use in calculating other load conditions. The use of circuit constants more readily permits the use of desirable approximations.

Application to Circle Diagrams—A further advantage of the use of general circuit constants is their application to the graphical solution of transmission problems involving transformers. The Dwight or other circle diagrams are applicable to this problem without change if general circuit constants are employed instead of constants applicable to the transmission line alone.

CORRECTION

In the JOURNAL for July 1921, p. 307, equation 11 should read $E_r = D_0 E_s - B_0 I_s$ and equation 12 should read $I_r = -C_0 E_s + A_0 I_s$ On p. 308, in the appendix, first equation, $\cos. \pi$ should read $\cos. 2\pi$.

Excavating with Electric Power in the Miami Conservancy District

L. C. McLURE
Industrial Sales Department,
Westinghouse Electric & Mfg. Company

THE City of Dayton, Ohio and the surrounding country, lying in the Miami Valley, has always been subject to periodic floods. The disastrous flood in the spring of 1913, which caused considerable loss of life and property, so crystallized the public opinion that the adjoining counties organized the Miami Conservancy District, to carry out an extensive program of excavation and dam construction to prevent such floods in the future. Earth dams are being thrown up which will extend across the valley to the hills on either side. Concrete covered openings are left in the dams, allowing the normal flow of water to pass. In periods of high water, the excess water will be retarded above the dams, allowing it to flow through at a safe rate.

As the surface of the land is rather flat, with rolling hills, the dams are long and require a large amount of material for their construction. Work on this project was started during the war, under unfavorable labor conditions; labor being expensive and hard to get at any price. These conditions demanded the use of excavation methods which requires the smallest number of workmen.

Drag-line excavators are employed to dig the material from the river bed and the valley above the dam site and load it into dump cars having a capacity of 12 cubic yards. The loaded cars are hauled to the base of the dam where the cars are dumped. A strong stream of water is then played on the pile of loose material, carrying away the earth held suspended in the

water. This mixture of water and earth is pumped to the top of the dam; where the water runs off, leaving the earth deposited on the dam. A drag-line, located on the top of the dam, is used to place the material where it is needed, and to give the sides of the dam their proper slope.

The electric drag-line excavator is constructed somewhat similar to a steam shovel. A car containing the main operating machinery is mounted on wheels or caterpillar tractors. In the front part are located the winding drums and their driving motors. In the rear of the car are located the control panels for the motors, and usually a bank of transformers. A long boom projects upward and forward from the front end of the machine. The cables from the winding drums run over sheave wheels on the extreme end of this boom and control the movements of the excavating bucket.

The bucket is pulled out to the end of the boom and dropped into the material. It is then dragged in toward the car until it is loaded. No thrusting motion is used, as in a shovel, but the weight and shape of the bucket are relied on to fill it. The loaded bucket is then hoisted and the whole drag line is turned until the bucket is in the right position for dumping, which is accomplished by lowering the open end and letting the material fall into the car.

Two motors are mounted in the car body. The hoist motor is connected through clutches to two drums, one of which hoists and lowers the bucket, while the other pulls the bucket through the material. The second motor rotates the drag-line between the digging and dumping positions.

The Conservancy District purchased, along with

FIG. 1—DRAG LINE USED FOR SMOOTHING THE SIDES OF A FILL

other excavating machinery, six Bucyrus motor driven drag-lines. Four of these are Class 24 size, having 200 hp motors on the hoist motion, and 100 hp motors on the swing motion. The other two are Class 175-B size on which 250 hp hoist motors and 125 hp swing motors are used. These motors are wound for three-phase, 60 cycles, 440 volts and are all of the heavy duty, reversing type. They are built with extra large bearings and shafts to make them suitable for the severe service; and are designed with small armature diameter, giving the low fly wheel effect which is so desirable in this service, where sudden stops, starts and frequent reversing is required.

Single-phase, 75 kv-a transformers are used to stepdown the 2300 volts power supply to the voltage used on the motors. A bank of these transformers is mounted on the ground near each drag line, separate mounting being preferred by the engineers of the Conservancy District. The low-voltage power is carried

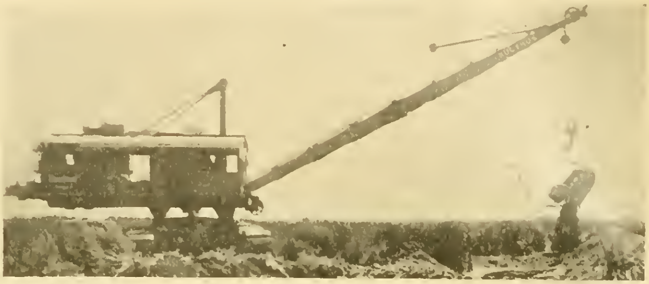

FIG. 2—DRAG LINE USED FOR EXCAVATING

to the drag line by a flexible cable, and when the machine moves any considerable distance, the transformers are disconnected and moved to the new location.

Full magnetic control is used for both main motors. The master switches and control levers for brakes and clutches are conveniently grouped at one point at the front of the car. Only one operator is required, who is so located that he can watch the various movements of the bucket. A motor driven air compressor supplies air for operating clutches and brakes.

These motor driven drag lines have been in service about three years and have given very satisfactory performance. The power consumption of one of the machines used on this project is given in Table I.

TABLE I—POWER CONSUMPTION

Cu. Yards excavated	77 050	72 136	35 310
Kw. hours used	60 500	45 700	42 600
Kw. hours per cu. yd.	0.78	0.63	1.2.

These records were taken on a Bucyrus, Class 24 drag line, deepening a river bed, loading gravel into cars of 12 cubic yard capacity. The three columns show the total volume of material handled, and kilowatt-hours used per month for three consecutive months.

The amount of labor required to operate these machines is small. Each drag line requires one operator and a helper who oils the machinery and attends to other minor duties. A considerable saving is made over the steam driven machines, because no men are required for firing the boilers, throwing coal up to the firing platform, or for bringing coal to the drag line.

Also, no coal cars are necessary, leaving the tracks and trains free for uninterrupted movement of material away from the excavator.

The necessity for maintaining a supply of pure boiler water does not exist; and this is of great importtance in winter months when frozen pipe lines will cause shut down of a steam driven machine. The motor driven machine has no stand-by losses when not operating; and when operations are resumed after an over-night or noon-time shut down, work can be started immediately upon closing the line switch, it not being necessary to wait until a boiler gets up steam pressure. For these reasons, these motor driven drag lines have made a record for low operating costs and for continuous operation, which shows them to be much superior to similar steam driven machines.

The Manufacture of Copper Wire and Strand

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COPPER wire and strand play a very important part in the electrical field and to those who have not had the opportunity of seeing them manufactured, a brief description of the several processes will be of interest. Refined copper, in its commercial form, is cast into bars which are usually about four inches square, fifty inches long and weigh 220 pounds. The average analysis of wire bar is:—

Copper	99.96
Oxygen	0.03
Silver	0.0022
Arsenic	0.0017
Antimony	0.0016
Nickel & Cobalt	0.0006
Bismuth	0.0004
Iron	0.0006
Selenium	0.0009
Sulphur	0.0020
	100.0000

The wire bars are first placed on a table in the rear of a bar-heating furnace and a pusher, operated by compressed air, moves them along into the furnace, which holds 100 bars lying side by side throughout its length. The furnace is heated by fuel oil burners located at the opposite end from that at which the bars enter. The bars are taken out of the furnace through a door, located near the heating chamber. As fast as they are taken out, more bars are pushed in at the rear end and the bars already in the furnace are moved toward the heated end and the discharge door. The heat travels the length of the furnace, the smoke and gases going out through a flue at the rear end.

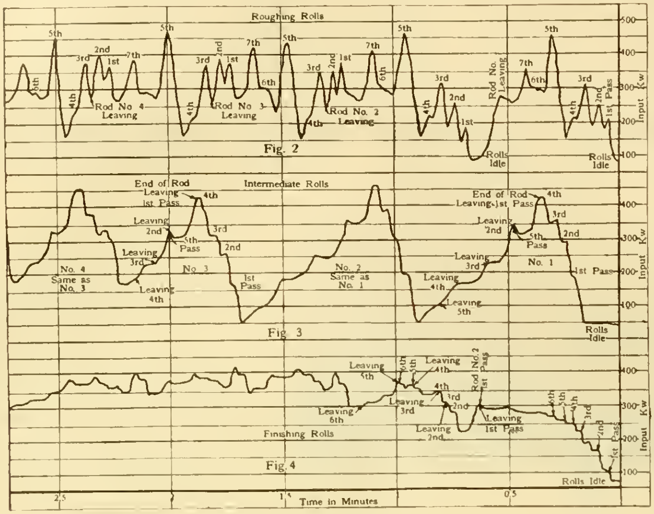
The bars are taken out of the furnace at the rate of 100 an hour. Thus it takes an hour for a given bar to travel through the furnace. In this way the heating takes place gradually and can be controlled so as to have each bar at the proper rolling temperature when it reaches the discharge door. The bars are taken out at the discharge door by a pair of tongs suspended from a trolley which runs in line with the first groove in the rough rolling mill. This mill consists of three rolls 18 inches in diameter and 64 inches long, one above the other, driven from a motor through a reducing gear unit and a set of pinions. The direction of rotation of these rolls is such that the bar, after entering the first groove, which is in the top and middle rolls, passes through this groove and drops down into position for entering the second groove, which is in the middle and bottom roll, and passes back through this second groove to the side of the mill from which it started. It is then raised into position for entering the third groove, which is next to the first groove. In this way, it passes back and forth through the mill seven times, each pass reducing the cross-section of the bar and increasing its length.

After leaving the roughing mill, the bar passes to the intermediate and finishing mills, consisting of five and six pairs of rolls respectively, each alternate pair rotating in opposite directions. When the rod, as it comes from the roughing mill, passes through the first pair of rolls in the intermediate mill, a man catches the end of it with a pair of tongs and starts it back through the next pair of rolls, the rod running in a loop on an inclined iron floor, which is on both sides of the rolls. This process is repeated until the rod has run through all the different pairs of rolls.

FIG. 1—GENERAL VIEW OF ROLLING MILL

The wire drawing process consists of drawing the rod through a succession of dies until its diameter has been reduced to the diameter of the wire required. For the larger sizes of wire the rod is drawn through one die at a time until it is finished, but for smaller wires the rod is placed on a continuous wire-drawing machine and is drawn through a succession of dies at the same time. These machines have a series of drawing rolls, each of which draws the wire through one die, after which it passes through the next smaller die

and on to the next drawing roll, this being repeated until it passes through the finishing die. It is then either drawn into a coil on a revolving block, or drawn and wound on a reel which is so driven as to take the wire as it is drawn through the last die. The drawing rolls and blocks on these machines run at increasing speeds proportioned so as to take care of the increasing length of wire produced by the elongation due to drawing.



FIGS. 2, 3 AND 4—POWER CURVES
Showing kilowatts required for the different passes through the various rolls.

The process of drawing the rod through the dies to the finished size hardens the copper. Wire drawn on these machines is shipped as "hard drawn wire". When "soft drawn wire" is required the hard wire is passed through an annealing furnace which renders the wire soft and pliable. Medium hard wire is produced by drawing the rod to a certain size which, after being annealed, will require just the necessary amount of further drawing to produce the degree of hardness specified. The dies used for wire drawing are small circular dies made of chilled cast iron, cast with a tapered hole and are reamed to exact size by hand. After the hole in the die wears and becomes too large for a given size of wire it is then reamed out to a larger size, this process being repeated many times.

The usual variation in diameter allowed on all wires of sizes No. 10 and smaller is one one-thousandth of an inch. Not only accuracy as to size is required, but it is necessary to shape the die so that it will hold its size within this limit after withstanding the wear of drawing a wire as long as four miles from one rod.

For making trolley wire to be furnished in long lengths, it is necessary to join a number of rods, which is done by brazing them with silver solder before drawing. A sufficient number of rods are brazed so as to produce a certain length of finished wire. In many cases this length is one mile, and the weight of the wires varies from 1687 pounds for 1-0 size to 3382 pounds for 4-0 size. After being brazed, the rods are drawn through two or more dies continuously and are wound on a reel at the same time. The dies used for making round trolley wire are made of chilled iron, the same as the dies for making smaller wires. For grooved, figure 8 and other shapes of trolley wire, the dies are made of the best quality of steel suitable for this purpose. They are carefully punched and sized, then hardened and polished. Under the best conditions a die will draw about five miles of wire, after which it has to be remade.

In the manufacture of strand or cables, the wire composing the strand or cable may be hard, medium hard or soft. The wire is either drawn on iron reels or wound on reels from coils and these reels are placed in the stranding machines. Strand such as is used for power transmission lines is made on a high-speed machine which will lay up six wires around a center wire.

FIG. 5—ROUGHING ROLLS
Showing flywheel and discharge end of heating furnace.

FIG. 6—INTERMEDIATE AND FINISHING ROLLS
With east loop pit in foreground.

Another machine consists of two revolving circular frames which usually revolve in opposite directions and in which iron reels containing the wire are placed. The first frame holds six reels, and as this frame revolves, the six wires are laid around a center wire which passes through the center of the frame. These seven wires then form the core of the cable and pass through the center of the next frame. The twelve wires which this second frame holds are laid around this core of seven wires, making a 19 wire srand or cable.

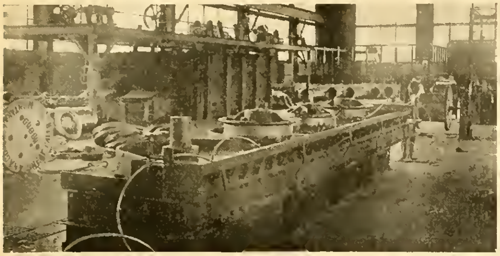


FIG. 7—A FOUR BLOCK DRAWING BENCH

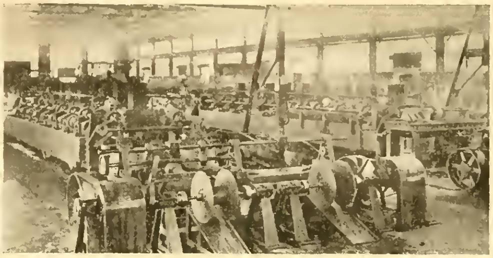


FIG. 8—FINISHING END OF A TEN DIE DRAWING MACHINE

Another machine of the same type but with three frames holding 6, 12, and 18 reels each, makes a cable of three layers or a total of 37 wires. If required, the cable of 37 wires is passed through the center of another machine and a further layer of 24 wires is added, making a 61-strand cable. It is also possible to pass this through another machine, adding 30 wires, if a cable of 91 wires is desired.

The completed cable passes around a revolving drum which takes it up as fast as it is twisted. It then passes from the drum to the reel on which it is to be shipped, which is driven so as to take it from the drum at the proper speed.

The revolving frames are driven through reversing and interchangeable gears, as is the take-up drum. The relation of the speed of the frame to the speed of the drum determines the pitch or lay of the wires in each layer, this lay usually varying with the number of wires.

FIG. 9—STARTING END OF A THREE FRAME 37 WIRE STRANDER

FIG. 10—FINISHING END OF STRANDER SHOWN IN FIG. 9

POWER REQUIREMENTS

The power is obtained from a substation located under the main floor and east of the loop pit of the finishing rolls, thus requiring no space on the main floor. In this substation is located the main 2200 volt bus with its accompanying oil circuit breakers, relays, instruments, etc., the main contactor panels for the roll motors, transformers for reducing 2200 volts to 440 volts for use in the smaller motors throughout the mill and lighting transformers. The process of wire making is admirably adapted to individual motor drive, and this is carried out with very few exceptions.

The roughing rolls are connected through a flexible coupling and 450 to 110 herringbone gear reduction to a 500 horse-power, 2200 volt, 450-442 r.p.m., wound rotor motor equipped with flywheel. The power used varies from 80 to 460 kw for red hot rods, as shown in Fig. 2. If a rod is held up for even a short period during its travel through the rolls and allowed to cool slightly, the power requirements are at least doubled. These heavy power swings cause an appreciable increase in the slip of the motor, thus bringing the flywheel into service to help over the peak. With the paper speed increased, as shown in Fig. 2, a very clear analysis is given of the power requirements for the different passes. Following through the first cycle, during which operation was retarded to allow one bar to leave rolls before second bar was started, the bar was of normal heat. On passes *1*, *2*, *3*, *4*, & *5* the bar passes completely through the rolls on each pass. However, by this time the bar has been elongated to such an extent that it is entered in pass *7* before leaving pass *6*. After this cycle was obtained, the second bar was started and rolls continued under normal operation, that is, the new bar started in pass *1* while the preceding bar is continuing through pass *7*.

The intermediate rolls are connected to a similar motor. However, the flywheel is omitted as the power swings are of less magnitude and they do not require its balancing effect. In Fig. 3, as in Fig. 2, the operation was retarded for a moment to allow two rods to make the entire travel singly then continue under normal operation. The rod has now elongated to such an extent that the end does not leave the pass *1* until after pass *4* is made. This is continued through normal operation with the exception that the second rod is entered in the pass *1* before the previous rod is out of pass *4*, thus giving the same peak and increasing the load factor on the motor.

The finishing roll motor also has no flywheel as its use is unwarranted as can be seen from Fig. 4. The power requirements of the different passes for a single rod are shown when the second rod enters the pass *1* just as the previous rod is leaving it. This allows two rods to be in the mill almost continuously, giving a comparatively constant load.

Control for each of the motors consists of a reversing controller which operates the control circuit for two triple-pole oil-immersed electrically-interlocked contactors mounted behind the main panel, one for forward and one for reverse direction of the rolls, also for eight electrically interlocked accelerating contactors mounted on the front of the panel. The accelerating contactors are in turn controlled by three current limit relays to insure proper acceleration of the motor regardless of the speed with which the controller handle is moved to either the forward or the reverse position. When number eight, or the final accelerating contactor, is closed, it opens the control circuit of the previous contactors thus opening the main contactors.

There is a maximum torque button installed near the controller to close No. 3 contactor and open No. 8, thereby cutting the proper amount of resistance in the rotor circuit to give maximum torque. When the button is released the contactors successively close back to normal or running position again. There are several stop buttons installed at different points on the rolls for use in emergency.

There are two exhaust systems for the rolls, the fan of each being driven by a 10 horsepower, 440 volt, 1200 r.p.m., squirrel-cage induction motor and piped to a funnel shaped opening above each pass, thus removing the smoke and copper dust from the operators.

The drawing benches are connected direct or through silent chain drives to 2200 volt induction motors either squirrel cage or wound rotor, as required. The earlier benches used the wound rotor motors due to higher starting torque and gradual acceleration. However, practice has shown that the squirrel cage motor is well adapted to this service as the motor is usually run at constant speed and the dies clutched in and out as desired. An exception to the above is the trolley bench, especially on figure eight or other than round or grooved wire as, on special shapes, it is desirable to start and accelerate slowly so that each block may be rigidly inspected. Therefore for this service the wound rotor motor is preferable.

ANNEALING FURNACE

The conveyors for drawing wire coils through the annealing furnace are operated by five horse-power direct-current adjustable-speed motors, having in addition to the shunt and commutating-pole windings, a compensating winding, giving sparkless commutation under all conditions. The speed ranges from 450 to 1800 r.p.m., which is varied by means of shunt field control.

STRANDING EQUIPMENT

The 7 stranding machines and 19 stranding machines are driven by 15 hp, 500 volt, direct-current shunt interpole motors. The 37 stranding machine is driven by a 440 volt, 720 r.p.m., wound rotor motor as, on account of the slow speed, an adjustable speed motor is not required.

LIGHTING

The lighting is symmetrically installed on roof trusses which clear the crane bridge about three feet. This not only facilitates initial installation, but makes a very convenient method of caring for lamp renewals and periodic cleaning of shades and lamps, as work may be done from the crane bridge. The original installation consisted of 18 inch flat shades with 750 watt lamps. However, these were later changed to shaped reflectors and 500 watt lamps over the rolls and standers, and 300 watt lamps for general illumination.

All lighting and power feeders are lead covered cables run under the floor in fibre ducts with manholes situated in desirable places for distribution. All disconnect switches ahead of the compensators and oil switches are totally enclosed and the frames of all machines are well grounded to avoid any possibility of accidents.

Electrical Characteristics of Transmission Circuits-XV

Synchronous Motors and Condensers for Power-Factor Improvement

WM. NESBIT

BEFORE discussing the employment of synchronous machinery for improving the power-factor of circuits, it may be desirable to review how a change in power-factor affects the generators supplying the current.

Fig. 61 shows the effect of in-phase, lagging and leading components of armature current upon the field strength of generators*. A single-coil armature is illustrated as revolving between the north and south poles of a bipolar alternator. The coil is shown in four positions 90 degrees apart, corresponding to one complete revolution of the armature coil. The direction of the field flux is assumed to be constant as indicated by the arrows on the field poles of each illustration. In addition to this field flux, when current flows through the armature coil another magnetic flux is set up, magnetizing the iron in the armature in a direction at right angles to the plane of the armature coil. This will be referred to as armature flux.

This armature flux varies with the armature current, being zero in a single-phase generator when no armature current flows, and reaching a maximum when full armature current flows. It changes in direction relative to the field flux as the phase angle of the armature current changes.

The revolving armature coil generates an alternating voltage the graph of which follows closely a sine wave, as shown in Fig. 61. When it occupies a vertical plane marked *start* no voltage is generated, for the reason that the instantaneous travel of the coil, is parallel with the field flux.** As the coil moves forward in a clockwise direction, the field enclosed by the armature coil decreases; at first slowly but then more rapidly until the rate of change of flux through the coil becomes a maximum when the coil has turned 90 degrees, at which instant the voltage generated becomes a maximum. As the horizontal position is passed the voltage decreases until it again reaches zero when the coil has traveled 180 degrees or occupies again a vertical plane. As the travel continues the voltage again starts to increase but since the motion of the coil relative to the fixed magnetic field is reversed the voltage in the coil builds up in the reverse direction during the second half of the revolution. When the coil has reached the two 270 degree position the voltage has again become maximum but in the opposite direction to that when the coil occupied the position of 90 degrees. When the coil returns to its original position at the start the voltage has again dropped to zero, thus completing one cycle.

If the current flowing through this armature coil is in phase with the voltage, it will produce cross magnetization in the armature core, in a vertical direction, as indicated by the arrows at the 90 and 270 degree positions. The cross magnetization neither opposes nor adds to the field flux at low loads and therefore has comparatively little influence on the field flux. At heavy loads, however, this cross magnetization has considerable demagnetizing effect, due to the shift in rotor position resulting from the shifting of the field flux at heavy loads.

If the armature is carrying lagging current, this current will tend to magnetize the armature core in such a direction as to oppose the field flux. This action is shown by the middle row of illustrations of Fig. 61. Under these illustrations is shown a current wave lagging 90 degrees representing the component of current required to magnetize transformers, induction motors, etc. When the lagging component of current reaches its maximum value the armature coil will occupy a vertical position (position marked start, 180 degrees and 360 degrees) and in this position the armature flux will directly oppose the field flux, as indicated by the arrows. The result is to reduce the flux threading the armature coil and thus cause a lowering of the voltage. This lagging current encounters resistance and a relatively much greater reactance, each of which consumes a component of the induced voltage, as shown in Fig. 62. When the armature current is lagging, the voltage induced by armature inductance is in such a direction as to subtract from the induced voltage, and thus the voltage is still further lowered, as a result of the armature self induction. In order to bring the voltage back to its normal value it will be necessary to increase the field flux by increasing the field current. Generators are now usually designed of sufficient field capacity to compensate for lagging loads of 80 per cent power-factor.

If the armature is carrying a leading current this leading component will tend to magnetize the armature core in such a direction as to add to the field flux.

*For a more detailed discussion of this subject the reader is referred to excellent articles by F. D. Newbury in the ELECTRIC JOURNAL of April 1918, "Armature Reaction of Polyphase Alternators"; and of July 1918, "Variation of Alternator Excitation with Load".

**For the sake of simplicity this and the following statements are based upon the assumption that armature reaction does not shift the position of the field flux. Actually, under load, the armature reaction causes the position of the field flux to be shifted toward one of the pole tips, so that the position of the armature coil is not quite vertical at the instant of zero voltage in the coil.

This action is shown by the bottom row of illustrations of Fig. 61. Under these illustrations is shown a current wave leading the voltage wave by 90 degrees. When the leading component of current reaches its maximum values, the armature coil will again occupy vertical positions, but the armature flux will add to that of the field flux, as indicated by the arrow. The resulting flux threading the armature coil is thus increased causing a rise in voltage. This leading current flowing through the generator armature encounters resistance and a relatively much greater reactance, each of which consumes a component of the induced voltage, as shown in Fig. 62. When the armature current is lead-

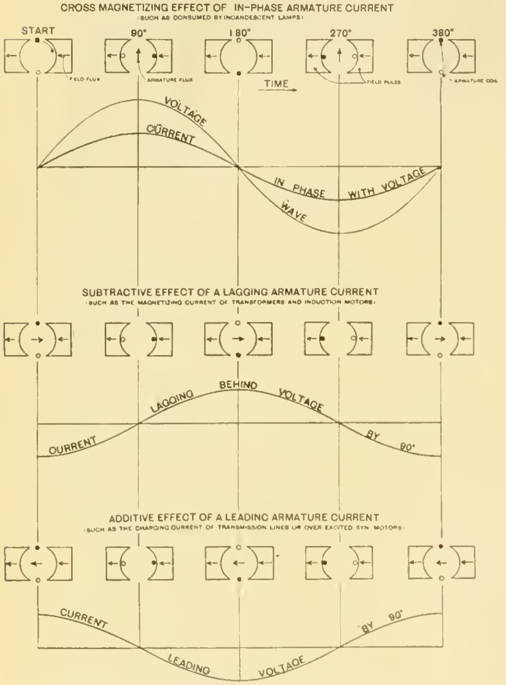


FIG. 61—EFFECT OF ARMATURE CURRENT UPON FIELD EXCITATION OF ALTERNATING-CURRENT GENERATORS

ing, the voltage induced by armature inductance is in such a direction as to add to the induced voltage and thus the voltage at the alternator terminals is still further increased as the result of armature self-induction. In order to reduce the voltage to its normal value it is necessary to decrease the field flux by decreasing the field current.

With alternators of high reaction the magnetizing or de-magnetizing effect of leading or lagging current will be greater than in cases where the armature reaction is low. For instance if the alternator is so designed that the ampere turns of the armature at full armature current are small compared to its field ampere turns, the voltage of such a machine would be less disturbed with a change in power-factor of the armature current than in an alternator having armature ampere turns large compared with its field ampere turns.

Modern alternators are of such design that when carrying rated lagging current at zero power-factor they require approximately 200 to 250 percent of their no-load field-current and when carrying rated leading current at zero power-factor they require approximately —15 to +15 percent of their no-load field current. Thus with lagging armature current the iron will be worked at a considerable higher point on the saturation curve and the heating of the field coils will increase because of the greater field current required.

The voltage diagrams of Fig. 62 are intended to show only the effect of armature resistance and armature reactance upon voltage variation. Voltage regu-

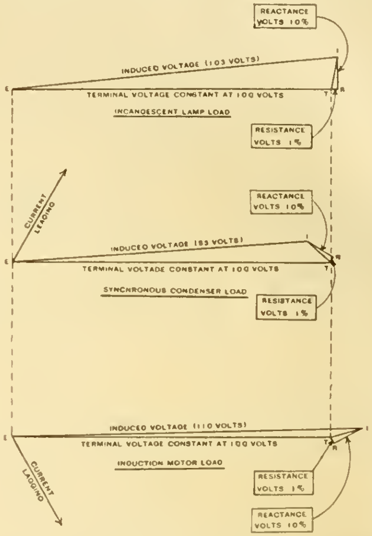


FIG. 62—VECTORS ILLUSTRATING THE EFFECT OF ARMATURE REACTANCE AND RESISTANCE UPON THE TERMINAL VOLTAGE FOR IN-PHASE, LEADING AND LAGGING CURRENTS

lation is the combined effect of armature impedance and armature reaction. Turbogenerators have, for instance, very low armature reactance but their armature reaction is higher, so that the resulting voltage regulation may not be materially different from that of a machine with double the armature reactance. Under normal operation armature reaction is a more potent factor in determining the characteristics of a generator than armature reactance. In the case of a generator with a short circuit ratio of unity, this total reactive effect may be due, 15 percent to armature reactance and 85 percent to armature reaction.

For the case illustrated by Fig. 62 the field flux corresponds to the induced voltage indicated, but the field current does not. The field current corresponds to a value obtained by substituting the full synchronous impedance drop for that indicated.

SYNCHRONOUS CONDENSERS AND PHASE MODIFIERS

The term "synchronous condenser" applies to a synchronous machine for raising the power-factor of circuits. It is simply floated on the circuit with its fields over excited so as to introduce into the circuit a leading current. Such machines are usually not intended to carry a mechanical load. When this double duty is required they are referred to as synchronous motors for operation at leading power-factor. On long transmission circuits, where synchronous condensers are used in parallel with the load for varying the power-factor, thereby controlling the transmission voltage, it is sometimes necessary to operate them with under excited fields at periods of lightloads. They are then no longer synchronous condensers but strictly speaking become synchronous reactors.

Whether synchronous motors for operation at leading power-factor, synchronous condensers or synchronous reactors be used they virtually do the same thing, that is; their function is to change the power-factor of the load by changing the phase angle between the armature current and the terminal voltage. They

TABLE R—SYNCHRONOUS CONDENSER LOSSES

Kv-a	Loss (Kw)	Kv-a	Loss (Kw)
100	12	3500	180
200	18	5000	220
300	22	7500	320
500	32	10000	420
750	47	15000	620
1000	55	20000	820
1500	70	25000	1000
2000	120	35000	1400
2500	130	50000	2000

are, therefore, sometimes referred to as "phase modifiers." This latter name seems more appropriate when the machine is to be operated both leading and lagging, as when used for voltage control of long transmission lines.

Rating — Synchronous condensers as regularly built may be operated at from 30 to 40 percent of their rating lagging, depending upon the individual design. Larger lagging loads result in unstable operation on account of the weakened field. Phase modifiers can be designed to operate at full rating, both leading and lagging, but they are larger, require larger exciters, have a greater loss and cost 15 to 20 percent more than standard condensers.

Starting—Condensers are furnished with squirrel-cage damper windings, to prevent hunting, which also provides a starting torque of approximately 30 percent of normal running torque. They have a pull-in torque of around 15 percent of running torque. The line current at starting varies from 50 to 100 percent of normal. The larger units are sometimes equipped for forced oil lubrication, which raises the rotor sufficiently to permit of oil entering the bearing, thus reducing the starting current.

Mechanical Load—Synchronous condensers are generally built for high speeds and equipped with shafts of small diameter. If they are to be used to transmit some mechanical power it may be necessary to equip them with larger shafts and bearings, particularly if belted rather than direct connected. If a phase modifier is to furnish mechanical energy and at the same time to operate lagging at times of light load for the purpose of holding down the voltage on an unloaded transmission line there may be danger of the machine falling out of step, if a heavy mechanical load occurs when the machine is operating with a weak field.

Losses—At rated full load leading power-factor the total losses, including those of the exciter, will vary from approximately 12 percent for the smallest capacity to approximately four percent for the larger capacity 60 cycle synchronous condensers. The approximate

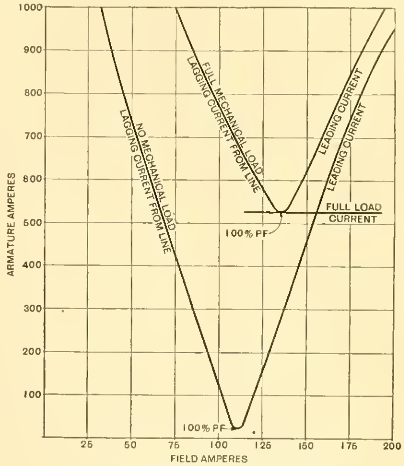


FIG. 63—V-CURVES OF A PHASE MODIFIER

values given in Table R may be of service for preliminary purposes.

"V" Curves—The familiar V curves shown in Fig. 63 serve to give some idea of the variation in field current for a certain phase modifier when operating between full load lagging and full load leading kv-a.* For this particular machine the excitation must be increased from 112 amperes at no load minimum input or unity power-factor to 155 amperes at full kv-a output leading or a range of 1.4 to 1 in. field excitation. For operation between full lagging and full leading, with no mechanical work done, the range of excitation is from 67 to 155 or 2.3 to 1.

Generators as Condensers—Ordinary alternators may be employed as synchronous condensers or synchronous motors by making proper changes in their field poles and windings to render them self-starting

*These curves have been reproduced from H. B. Dwight's book "Constant Voltage Transmission".

and safely insulated against voltages induced in the field when starting.

Where transmission lines feed into a city net work and a steam turbine generator station is available these generating units can serve as synchronous condensers by supplying just enough steam to supply their losses and keep the turbine cool. When operated in this way they make a reliable standby to take the important load quickly in case of trouble on a transmission line.

Location for Condensers—The nearer the center of load that the improvement in power-factor is made the better, as thereby the greatest gain in regulation, greatest saving in conductors and apparatus are made since distribution lines, transformers, transmission lines and generators will all be benefited.

How High to Raise the Power-Factor—Theoretically for most efficient results the system power factor should approach unity. The cost of synchronous apparatus having sufficient leading current capacity to raise the power-factor to unity increases so rapidly as unity is approached, as to make it uneconomical to carry the power-factor correction too high. Not only the cost but also the power loss chargeable to power-factor improvement mounts rapidly as higher power-factors are reached. This is for the reason that the reactive kv-a in the load corresponding to each percent change in power-factor is a maximum for power-factors near unity. It usually works out that it doesn't pay to raise the power factor above 90 to 95 percent, except in cases where the condenser is used for voltage control, rather than power-factor improvement.

DETERMINING THE CAPACITY OF SYNCHRONOUS MOTORS AND CONDENSERS FOR POWER-FACTOR IMPROVEMENT

A very simple and practical method for determining the capacity of synchronous condensers to improve the power-factor is by aid of cross section paper. A very desirable paper is ruled in inch squares, sub-ruled into 10 equal divisions. With such paper, no other equipment is required.

With a vector diagram it is astonishing how easy it is to demonstrate on cross section paper, the effect of any change in the circuit. A few typical cases are indicated in Fig. 64. These diagrams are all based upon an original circuit of 3000 kv-a at 70 percent power-factor lagging, shown by (1). It is laid off on the cross section paper as follows. The power of the circuit is 70 percent of 3000 or 2100 kw, which is laid off on line *AB*, by counting 21 sub-divisions, making each sub-division represent 100 kw or 100 kv-a. Now lay a strip of blank paper over the cross section paper and make two marks on one edge spaced 30 sub-divisions apart. This will then be the length of the line *AC*. This blank sheet is now laid over the cross section paper with one of the marks at the edge held at the point *A*. The other end of the paper is moved downward until the second mark falls directly below the point *B* thus locating point *C*. The length of the line *BC* represents the lagging reactive kv-a in the circuit, in this case 2140 kv-a.

Diagram (2) shows the effect of adding a 1500 kv-a synchronous condenser to the original circuit. The full load loss of this condenser is assumed as 70 kw. The resulting kv-a and power-factor are determined as follows: Starting from the point *C* trace to the right a line 0.7 of a division long. This is parallel to the line *AB* for the reason that it is true power, so that there is now 2170 kw true energy. The black triangle represents the condenser, the line *CD*, 15 divisions long, representing the rating of the condenser. In this case, however, the vertical line is traced upward in place of downward, because the condenser kv-a is leading. This condenser results in decreasing the load from 3000 kv-a at 70 percent power-factor to 2275 kv-a at 95.4 percent power-factor. The line *AD* represents in magnitude and direction, the resulting kv-a in this circuit. The power-factor of the resulting circuit is the ratio of the true energy in kw to the kv-a or 95.4 percent, in this case. Since the line *AD* lays below the line *AB*, that is in the lagging direction, the power-factor is lagging.

Diagram (3) is the same as (2) except that the condenser is larger, being just large enough to neutralize all of the lagging component of the load, resulting in a final load of 2215 kw at 100 percent power-factor. Diagram (4) is similar to (3) except that a still larger condenser is shown. This condenser not only neutralizes all of the lagging kv-a of the load but in addition introduces sufficient leading kv-a into the circuit to give a leading resultant power-factor of 94 percent with an increase in kv-a of the resulting circuit from 2215 of (3) to 2400 kv-a of (4).

Diagram (5) illustrates the addition to the original circuit of a 100 percent power-factor synchronous motor of 600 hp. rating As this motor has no leading or lagging component, there is no vertical projection. The power-factor of the circuit is raised from 70 to 77 percent as the result of the addition of 500 kw true power (load plus loss in motor) to the circuit. A resistance load would have this same effect.

Diagram (6) shows a 450 kw (600 hp.) synchronous motor of 625 kv-a input at 80 percent leading power-factor added to the original circuit. The input to this motor (including losses) is assumed to be 500 kw. The resulting load for the circuit is 3150 kv-a at 82.5 percent lagging power-factor.

The Diagram (7) shows an 850 kw, (1140 hp.) synchronous motor generator of 1666 kv-a input at 60 percent power-factor leading added to the original circuit. This gives a resulting load of 3200 kv-a at 96.9 percent lagging power-factor.

Diagram (8) shows the addition to the original circuit of the following loads, including losses.

A 550 kw synchronous converter at 100 percent power-factor.
A 650 kw induction motor at 70 percent lagging power-factor.
A 500 kw synchronous motor.

The resultant load of this circuit is 3800 kw, and if a power-factor of 95 percent lagging is desired the total kv-a will be 4000. The line *AD* may be located by a piece of marked paper and the capacity of the necessary synchronous motor scaled off. This is found to be 1650 kv-a at 30.3 percent power-factor.

The Circle Diagram—The circle diagram in Fig. 65 shows the fundamental relations between true kw, reactive kv-a and apparent kv-a corresponding to different power-factors, the values upon the chart being read to any desired scale to suit the numerical values of the problem under consideration. This diagram is suffi-

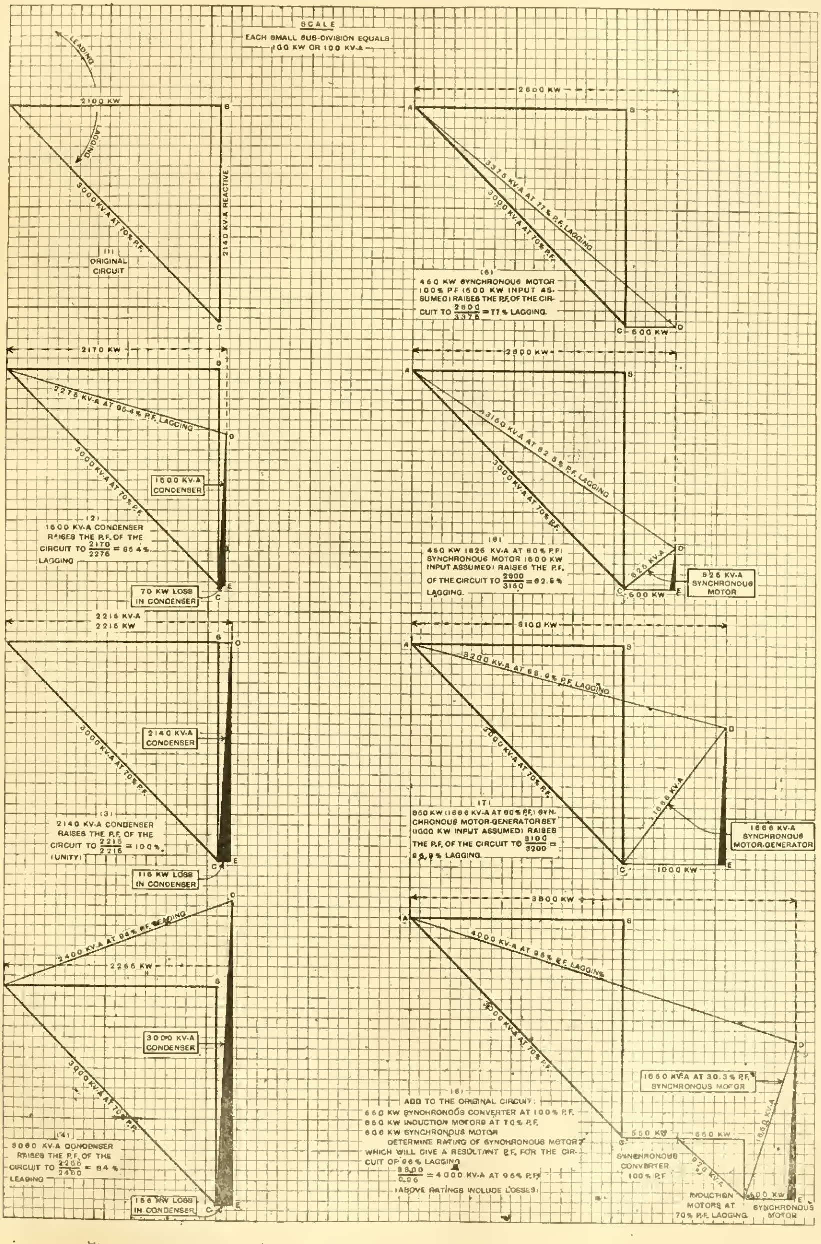


FIG. 64—EXAMPLES IN POWER-FACTOR IMPROVEMENT

ciently accurate for ordinary power-factor problems. In place of drawing out the vector diagrams as just explained they are traced out with a pin point on the circle diagram.

Assume again a load of 2100 kw at 70 percent power-factor lagging, and that the power-factor is to be raised to 95.4 percent as in (2) of Fig. 64, and that the loss in the condenser necessary to accomplish this is again taken as 70 kw. The capacity of the synchronous condenser may be traced on the circle diagram as follows: From the true power load of 2100 kw (top horizontal line) follow vertically downward until the diagonal line representing 70 percent power-factor is reached. This is opposite 2140 kv-a reactive component. From the point thus obtained, go horizontally to the right a distance representing 70 kw power. From this point go vertically upward until the diagonal line representing 95.4 percent power-factor is reached. Then read the amount of reactive kv-a (640) corresponding to this last point. The original lagging component of 2140—640=1500 kv-a which is approximately the capacity of the condenser necessary to accomplish the above results. Actually the rating of the condenser would be the hypotenuse rather than the vertical projection. The error in assuming the vertical projection as the rating of the condenser is negligible unless the condenser furnishes mechanical power, in which case the hypotenuse should be marked on a separate strip of paper and its length determined from the kv-a scale.

ADVANTAGE OF HIGH POWER-FACTOR

Less Capacity Installed—Low power-factors demand larger generators, exciters, transformers, switching equipment and conductors. Loads of 70 percent power-factor demand equipment of 28 percent greater capacity than would be required if the power-factor were 90 percent. The cost of apparatus for operation at 70 percent power-factor would be approximately 15 percent greater than the cost of similar apparatus for 90 percent power-factor operation, since the capacity of apparatus to supply a certain amount of energy is inversely proportional to the power-factor.

Higher Efficiency—Assume that the power-factor of a 1000 kv-a (700 kw at 70 percent power-factor) transmission circuit is raised to 90 percent. As the cop-

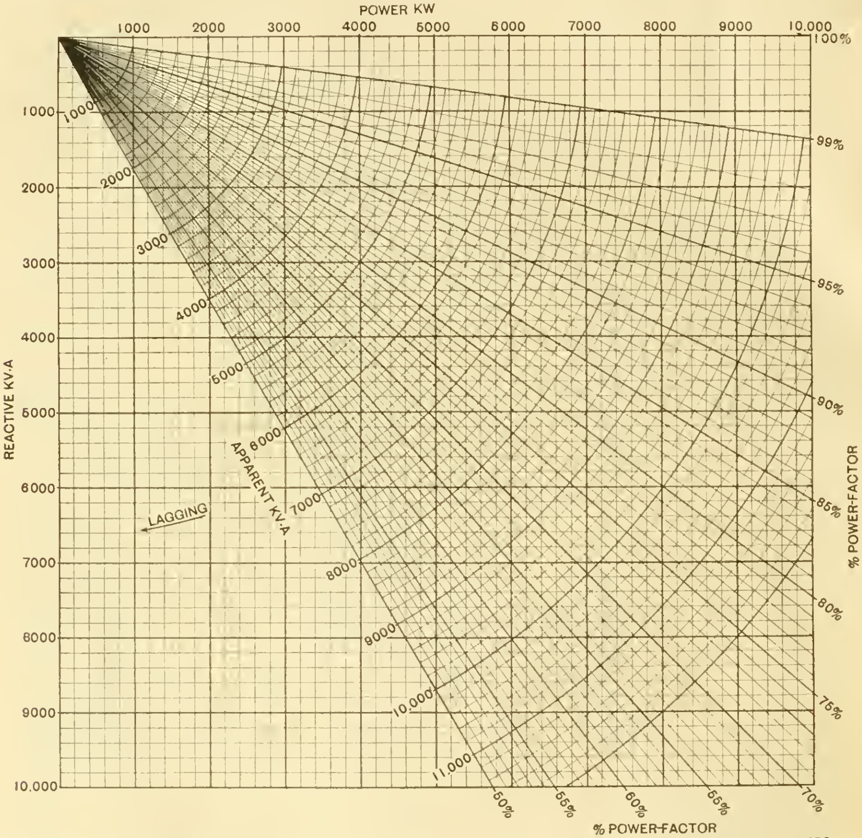


FIG. 65—RELATION BETWEEN ENERGY LOAD, APPARENT LOAD AND REACTIVE KV-A FOR DIFFERENT POWER FACTORS

per loss varies as the square of the current, raising the power-factor reduces the copper loss approximately 40 percent. If we assume an efficiency for the generator of 93 percent (one percent copper loss); for combined raising and lowering transformers 94 percent (three percent copper loss) and for the transmission line 92 percent, the saving in copper loss corresponding to 90 percent power-factor operation would be as follows:

Generators	0.4 percent
Transformers	1.2 percent
Transmission line	3.2 percent
Total	4.8 percent or approximately 33 kw.

To raise the power-factor to 90 percent would require a synchronous condenser of 375 kv-a capacity. This size condenser would have a total loss of about 30 kw, resulting in a net gain in loss reduction of three kw. Against this gain would be chargeable, the interest and depreciation of the condenser cost with its accessories, also any cost of attendance which there might be in connection with its operation. It is evident that in this case it would not pay to install a condenser if increased efficiency were the only motive.

TABLE S—COST OF POWER-FACTOR CORRECTION WITH SYNCHRONOUS MOTORS

Syn. Motor Kv-a	Motor Will Furnish		Chargeable to Power-Factor Correction	
	Mech. Kw	Leading Kv-a	Loss Kw	Difference in Price
140	100	100	1.6	$500.00
280	200	200	2.5	500.00
420	300	300	5.0	500.00
700	500	500	8.0	800.00
1050	750	750	9.0	1000.00
1400	1000	1000	14.0	1200.00

The improvement in power-factor can be more cheaply and efficiently obtained by the installation of one or more synchronous motors designed for operation at leading power-factor. Sufficient capacity of these will give, in addition to mechanical load, sufficient leading current to raise the power-factor to 90 percent. The extra expense and increased loss of synchronous motors enough larger to furnish the necessary leading component for power-factor correction is very small. Table S gives in a very approximate way, some idea of the amount of loss and proportional cost of synchronous motors chargeable to power-factor improvement when delivering both mechanical power and leading current.

Thus if a synchronous condenser is used on the above circuit there is a loss of 30 kw, chargeable to power-factor improvement, whereas if a synchronous motor of sufficient capacity (530 kv-a) to give 375 kw mechanical work and at the same time the necessary 375 kv-a leading current for power-factor improvement, the extra loss chargeable to power-factor improvement would be something like six kw. The increased cost of a synchronous motor to furnish 375 kv-a leading current in addition to 375 kw power would be about $600 whereas the cost of a 375 kv-a condenser would be in the neighborhood of $4000. Varying costs and designs make cost and loss values unreliable. They are given here only to illustrate the points which should be considered when considering synchronous motors vs synchronous condensers.

Improved Voltage Regulation—The voltage drop under load for generators, transformers and transmission lines rapidly increases as the power-factor goes down. Table T gives an idea of the variation in voltage drop corresponding to various power-factors at 60 cycles.

Automatic voltage regulation may be used to hold the voltage constant at the generators or at some other point, but it cannot prevent voltage changes at all points of the system.

Increased Plant Capacity—The earlier alternators were designed for operation at 100 percent power-factor with prime movers, boilers, etc. installed on the same basis. Increasing induction motor loads have resulted in power-factors of 70 and 80 percent. As a result, some of the older generating stations are being operated with prime movers, boilers etc. underloaded because the 100 percent power-factor generators which they drive limit the amount of power that can be generated without endangering the generator windings. This condition some times makes it necessary to operate three units, where two might be sufficient to carry the load at unity power-factor. The shutting down of a unit would result in a considerable saving in steam consumption. A recent case came up of a transmission line 30 miles long, fed at each end by a small generating station. On account of heavy line drop it was necessary to operate both stations to furnish the comparatively light night load. Investigation developed that by installing a synchronous condenser at one of these terminal stations for reducing the voltage drop in the line, one generating station could be shut down during the night, thereby resulting in a very large annual saving in coal and labor bills.

TABLE T—EFFECT OF POWER-FACTOR ON VOLTAGE DROP

Percent Power-Factor	100	90	80	70
Generators *(older design)	8.0	-	25.0	-
Transformers	1.2	4.1	4.9	5.5
Transmission line	7.9	13.0	14.2	15.2

A station may have some generating units designed for 100 percent power-factor and other units designed for 80 percent power-factor; or again, where two generating stations feed into the same transmission system, one may have 100 percent power-factor generating units and the other 80 percent power-factor

*The present-day design of maximum rated generators with a short-circuit ratio of about unity will barely circulate full-load current with normal no-load excitation. Under such conditions the terminal voltage would be practically zero regardless of the power-factor.

generating units. In such cases, the field strength of the generators may be so adjusted as to cause the 80 percent power-factor units to take all the lagging current, thus permitting the 100 percent power-factor units to be loaded to their full kw rating.

BEHAVIOR OF A. C. GENERATORS WHEN CHARGING A TRANSMISSION LINE*

It has been shown above how leading armature current, by increasing the field strength, causes an increase in the voltage induced in the armature of an alternator and consequently an increase in its terminal voltage. It was also shown that the terminal voltage is further increased as result of the voltage due to self induction adding vectorially to the voltage induced in the armature.

If an alternator with its fields open is switched onto a dead transmission line having certain electrical characteristics, it will become self exciting, provided there is sufficient residual magnetism present to start the phenomenon. In such case, the residual magnetism in the fields of the generator will cause a low voltage to be generated which will cause a leading line charging current to flow through the armature. This leading current will increase the field flux which in turn will increase the voltage, causing still more charging current to flow, which in turn will still further increase the line voltage. This building up will continue until stopped by saturation of the generator fields. This is the point of stable operation. Whether or not a particular generator becomes self exciting when placed upon a dead transmission line depends upon the relative slope of the generator and line characteristics.

In Fig. 66 are shown two curves for a single 45 000 kv-a, 11 000 volt generator, the charging current of the transmission line being plotted against generator terminal voltage. One curve corresponds to zero excitation, the other curve to 26.6 percent of normal excitation. A similar pair of curves correspond to two duplicate generators in parallel**. The straight line representing the volt-ampere characteristics of the transmission line fed by these generators corresponds to a 220 kv, 60 cycle, three-phase transmission circuit, 225 miles long, requiring 69 000 kv-a to charge it with the line open at the receiving end.

The volt-ampere charging characteristic of a transmission line is a straight line, that is, the charging current is directly proportional to the line voltage. On the other hand the exciting volt-ampere characteristic for the armature has the general slope of an ordinary saturation curve.

*For a more detailed discussion of this subject see the following articles:—"Characteristics of Alternators when Excited by Armature Currents" by F. T. Hague, in the JOURNAL for Aug. 1915; "The Behavior of Alternators with Zero Power-Factor Leading Current" by F. D. Newbury, in the JOURNAL for Sept. 1918; "The Behavior of A. C. Generators when Charging a Transmission Line" by W. O. Morris, in the *General Electric Review* for Feb. 1920.

**It is assumed that with the assumed field current such generators can be synchronized and held together during the process of charging the line.

If the alternator characteristic lie above the line characteristic at a point corresponding to a certain charging current the leading charging current will cause a higher armature terminal voltage than is required to produce that current on the line. As a result the current and voltage will continue to rise until, on account of saturation, the alternator characteristic falls until it crosses the line characteristic. At this point the voltage of the generator and that of the line are the same for the corresponding current. If on the other hand the alternator characteristic falls below the line characteristic the alternator will not build up without permanent excitation.

As stated previously, whether or not a generator becomes self-exciting when connected to a dead transmission line depends upon the relative slopes of generator and transmission line characteristics. The relative slopes of these curves depend upon:—

a—The magnitude of the line charging current.
b—The rating of the generators compared to the full voltage charging kv-a of the line.
c—The armature reaction. High armature reaction, (that is low short-circuit ratio) favors self-excitation of the generators.
d—The armature reactance. High armature reactance also favors self-excitation of the generators.

Methods of Exciting Transmission Lines—If the relative characteristics of an alternator and line are such as to cause the alternator to be self-exciting, this condition may be overcome by employing two or more

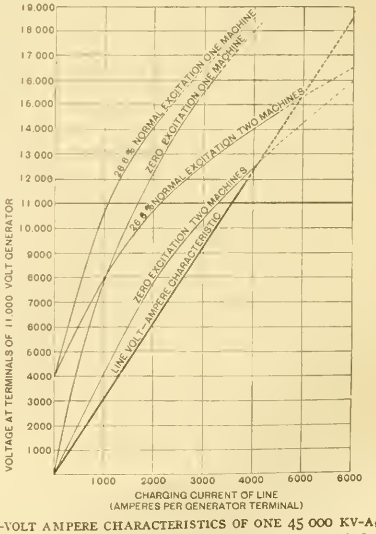


FIG. 66—VOLT AMPERE CHARACTERISTICS OF ONE 45 000 KV-A, 11 000 VOLT GENERATOR; TWO DUPLICATE 45 000 KV-A GENERATORS; AND A THREE-PHASE, SINGLE-CIRCUIT, 220 KV TRANSMISSION LINE

alternators (provided they are available for this purpose) to charge the transmission line. The combined characteristics of two or more alternators may be such as to fall under the line characteristic, in which case the alternator will not be self-exciting. In such case, the alternators could be brought up to normal speed, and given sufficient field charge to enable them to be

synchronized and held in step, after which they could be connected to the dead transmission line and their voltage raised to normal.

Generators as normally designed will carry approximately 40 percent of their rated current at zero leading power-factor. If more than this current is demanded of them they are likely to become unstable in operation. By modifying the design of normal alternators so as to give low armature reaction, they may be made to carry a greater percentage of leading current. If the special design is such that with zero voltage field excitation when carrying half the line charging kv-a, the armature voltage will not exceed 70 percent of normal, this reduced voltage will result in a line charging kv-a of half of normal value. Specially designed alternators usually result in larger and more costly machines and the gain resulting in the special design is usually not sufficient to warrant the extra cost.

If a single generator with its field circuit open were connected to a dead transmission circuit such as the one whose volt-ampere characteristics are shown in Fig. 66, and there were sufficient residual magnetism to start the phenomenon, the generator voltage would rise to approximately double normal value before the point of staple operation is reached. If, however, two generators having 26.6 percent of normal excitation were paralleled and connected to this circuit, a point of staple operation would be reached at a terminal voltage of approximately 15 500 volts. Actually stable operation would be reached at a somewhat less terminal voltage for the reason that the line would probably not be open at the receiving end, but would probably have the lowering transformers connected to it. In such case the magnetizing current required for lowering transformers would lower the receiving end voltage, resulting in less line charging current.

In either case the curves of Fig. 66 show that either more than two generators will be required to charge the line when unloaded, or some other method of charging must be resorted to. Reactance coils could be used at the receiving end to furnish lagging current for neutralizing some of the line charging current, but there might be difficulty in removing these from the circuit when the line is fully charged. At the present time it is expected that the problem of charging long transmission lines may usually be solved by starting one or more generators with sufficient field strength to permit them to be synchronized and held in step. One or more phase modifiers with under-excited fields may then be connected to the line at the receiving end and brought up to normal speed with the generators. Such a method of solving this problem has been employed by the Southern California Edison Company.

TABLE U—INSTALLATIONS OF LARGE PHASE MODIFIERS (1921)
By American Manufacturers

Kv-a	R.P.M.	Volta	Cycles	No. of Units	Date of Order	NAME AND LOCATION
30 000	600	6600	50	1	1919	So. Cal. Ed. Co., Los Angeles, Cal.
20 000	600	11 000	60	2	1921	Pacific Gas & Elec.
15 000	375	6600	50		1912	Soutbern Cal. Ed. Co., Los Ang., Cal.
15 000	375	6600	50	1	1912	Pacific Lt. & Pr. Co.
12 600	500	22 000	50	2	1918	Andhra Valley, India
7500	400	6600	60	2	1913	Utah Pr. & Lt. Co., Salt Lake, Utah
7500	400	6600	60	2	1916	Canton El. Co., Canton, Ohio
7500	600	13 800	60	1	1917	Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
7500	600	13 800	60	1	1917	New England Pr. Co., Worcester, Mass.
7500	720	13 800	60	1	1918	New England Pr. Co., Fitchburg, Mass.
7500	800	11 500	40	1	1918	Adirondack El. Pwr. Corp., Watervliet, New York
7500	750	11 000	50	1	1919	Energia Electrica de Cataluna, Barcelona, Spain
7500	600	11 000	60	1	1920	Duquesne Light Co.
7500	600	1200	60	2	1918	J. G. White, Engineers
7500	600	11 000	60	1	1918	Duquesne Light Co.
7500	600	11 000	60	1	1916	Duquesne Light Co.
7500	600	11 000	60	2	1917	Duquesne Light Co.
6500	750	2200	50	1	1917	Shanghai Municipal Council, Shanghai, China
6000	500	16 500	50	1	1914	So. Cal. Ed. Co., Los Angeles, Cal.
5000	600	7200	60	1	1916	Pac. Pwr. & Lt., Kennewick, Wash.
5000	500	6600	50	2	1915	Tata Hydro El. Pr. & S. Co., India
5000	750	6600	50	3	1917	Ebro Irrigation & Pr. Co., Barcelona, Spain
5000	750	11 500	50	1	1919	Societa Lombarda Distribuziona Energia Elettrica, Italy
6000	600	2300	60	1	1918	Turnbull Steel Co., Warren, Ohio
5000	720	2300/ 4000	60		1921	Public Service of N. Ill.
5000	720	11 000	60	1	1921	Takata & Co., Japan.
5000	600	13 200	60	1	1919	Conn. Lt. & Pr. Co.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

2000—HEATING OF IRON SURROUNDING A CONDUCTOR—When brought through the cast iron frame of an alternating-current generator in individual holes, generator leads cause excessive heating, yet high voltage roof bushings are constructed for currents of 300 amperes with cast-iron base rings and cast-iron foundation rings. "Crosby" cable clamps each consisting of a cast-iron yoke with a wrought iron U-bolt have been successfully used to splice transmission line and feeder cables carrying several hundred amperes, yet bus-bar clamps for alternating-current work are commonly constructed with one part alloy. At commercial frequencies (1) what are the permissible limits of current, (2) cross-section of the surrounding iron, and (3) nearness to the conductor within which objectionable heating will not occur when one or two conductors only of a three-phase alternating-current circuit are surrounded by cast iron or structural steel? A. R. (MONT.)

Regarding the heating of iron parts,

each electrical application has its own problems, depending on the relative arrangement of these parts and the current carrying conductors. Therefore, no definite general limits as to the distance of iron parts from conductors, cross-section of iron and magnitude of current can be given. The temperature rise of the iron is directly proportional to the iron loss and inversely proportional to the exposed surface to dissipate the heat caused by this loss. Hence, the limiting amount of current and nearness to the iron depend on the shape as well as the cross-section of the iron. The problem, therefore, resolves itself into the limiting or permissible flux densities and frequencies, which cause the iron loss and hence the heating. These will be different for each local condition. For instance, in roof bushings, the iron is a considerable distance from the conductor, on account of the thick insulation between them, while on bus-bars the clamp is placed directly around the bar. Then, for the same current, the flux density in the cast-iron bus-bar clamp, and hence the heating, will be much greater than in the roof bushing base rings. In nearly all cases, the cast-iron bus-bar clamps are either bolted with brass bolts, or made of one part alloy, whereas, in roof bushings, the base rings may be made of cast-iron up to about 800 amperes capacity. Above this limit, the base rings must either be made of alloy or split in halves and insulating material placed between the halves. On alternating-current generators, it is standard practice to bring all the leads out through the same hole in the frame to avoid heating of the frame. In one particular case of a two-phase, 350 kv-a vertical generator, where the leads were brought out through different holes in the frame, the heating was sufficient to warrant changing the leads so as to have their magnetizing effect neutralized. The frame of the machine was one inch thick, and each of the four leads carried about 1600 amperes. On account of the high stresses to which the windings of turbogenerators are subjected on short-circuit, the coil extensions are additionally braced by means of wooden blocks bolted (through the coil extensions) to brackets on the frame. During an impedance test on a 6000 kv-a, 13 200 volt, 25 cycle machine, the bolts holding these braces, which are made of iron, and are about 9/16 inches in diameter, and 10 inches long, became so hot that it was necessary to shut the machine down and replace the iron bolts by bronze ones. Each armature coil carried approximately 790 amperes, and the winding was so arranged that these bolts were being cut by a magnetic field produced by the armature magnetomotive-force having a maximum value of approximately 18 000 ampere-turns. Although all the bolts were under approximately the same magnetizing force, the flux density, and hence the heating, varied with the relative position of the different bolts to other iron parts. Naturally, the bolts nearest the core of the machine were considerably hotter than the others. The bolts on another machine of similar contruction, rated at 5000 kv-a, 12 000 volts, 60 cycles, became hot enough to melt the paraffine in the supporting blocks. During a 150 percent load short-circuit on an 8000 kv-a, 11 000 volts, 60 cycle machine, having 48 coils, each carrying approximately 700 amperes, the following temperature rises were observed on the bolts; maximum, 82.5 degrees C., mean, 59.6 degrees C., minimum, 31 degrees C. It was necessary to substitute bronze bolts for only the first three rows of bolts nearest the core of the machine. On still another machine, rated at 5000 kv-a, 13 200 volts, 60 cycles, a comparative test was made showing the temperature rises on both bronze and iron bolts.

The resultant rises were as follows:—

	Bronze Bolts	Iron Bolts
Max.	7.5	18
Mean	10.7	29.2
Min.	14.5	49.0

On transformers, it has been found that approximately 1200 amperes at 25 cycles and 700 amperes at 60 cycles is as high a current as can be brought out through three-inch holes in a transformer tank top 0.5 inch thick, before injurious heating is encountered. The above figures, of course, apply only to specific instances, but may be indicative in a general way of the limiting value of the factors concerned. M. W. S.

2001—PARALLELING TRANSFORMERS — Given one three-phase, 25 cycle, 12 000 to 600 volt transformer connected star on the high-tension side and delta on the low-tension side, and one bank of three single-phase, 25 cycle, 12 000 to 600 volt transformers connected delta on the high-tension side and delta on the low-tension side, is there any convenient way in which these two sets can be operated in parallel without redesigning the coils of one set? It will be noted that one set is connected "star-delta" and the other set "delta-delta", with both sets having the same voltage ratio. T. B. (ONT.)

It is not possible to connect these banks in parallel without changing the windings of one of the banks. There is 30 degrees phase displacement between a "star-delta" and a "delta-delta" connected bank of transformers and if connected in parallel a short-circuit would result. See article on "Phasing Out High-Tension Lines" by E. C. Stone, in the JOURNAL for Nov. 1917, p. 448. H. F.

2002—TURBOGENERATOR FIELD COILS— Recently I had occasion to cut two coils out of a turbogenerator winding. The machine has operated satisfactorily since, but I would like to know how far I can go without getting into trouble, due to mechanical unbalance of the rotor. The coils cut out were about 120 geometrical degrees apart, referred to periphery of the stator. In case vibration should set in, would it remedy matters to cut out another coil so as to have the coils cut out 120 degrees apart? In case the coils had been about 90 degrees apart would it be satisfactory to cut out two more so as to establish a 90 degree relationship? C. D. M. (WYO.)

The possibility of operating a machine with coils or parts of coils in either field or armature cut out of circuit depends, to a large extent, on the type of connection in the armature winding. Field coils should never be cut out of circuit if it is possible to avoid it. This is particularly the case if the armature windings are grouped in parallel circuits. Magnetic unbalance, resulting in vibration, nearly always follows any dissymmetry in the field exciting circuit. A coil could be cut out of a two pole rotor while one coil could not be cut out of a four pole rotor without causing mechanical unbalance. Armature or stator coils, on the other hand, can frequently be cut out without causing trouble in the so-called open type winding. In the case of the armature windings, there is little danger from mechanical unbalance, and the principle requirement is that there be no unbalance of voltage in a closed circuit. In the open type of winding, if the groups in any one phase are in parallel circuits, then corresponding coils in all parallel circuits should be cut out of the circuit. If this precaution is followed, there is, in general, little danger of doing damage to the machine by removing from the circuit coils not in excess of five percent of the total. This limit is determined by the extent to which the magnetic flux can be increased. An open winding, made unsymmetrical by removing coils from some phases, and not others, causes unsymmetrical currents to flow between it and all symmetrically connected machines on the same circuit. The result of these currents is to set up eddy currents in the damper circuits, or faces, of all machines on the system. In general these currents will be too small to cause appreciable heating, and therefore, can be neglected. R. E. G.

2003—CHANGING METER DIAL CONSTANTS—It is not an uncommon thing to patch up a meter installation for a short period with a piece of apparatus that is not regular, or change a meter from a line of one voltage to another of a higher or lower potential. This might mean that a current transformer burnt out which had to be replaced with one of a different ratio until repairs could be made; a meter might burn out and be replaced with one that was for a different current ratio, or a meter that has been in service on a 2200 volt circuit having, say, a current ratio of 400 to 5 and a potential ratio of 20 to 1 may be placed in a 33 000 volt circuit having a current ratio of 100-5 and a potential ratio of 300 to 1. In making these changes it is necessary to give the meter a new dial constant, and this is quite complicated where both current and potential transformers ratios have been changed. It is to this end that I would like to know what rule or method to use in figuring out what the new or changed dial constant should be. It is assumed that the meters are polyphase watthour meters having a 5 ampere current and a 110 volt potential winding. As an example, what would be the new dial constant of a meter connected to a three-phase, 33 000 volt line with current transformer ratio 100 to 5 ampere and potential ratio of 300 to 1. This meter had a dial constant of 10 when connected to a three-phase 110 volt line with a current transformer ratio of 60 to 1. W. H. H. (N. Y.)

A polyphase watthour meter is usually equipped with a register, the kw capacity of which is equal to $\frac{2 \times V \times A}{1000}$ where V = the rating of the meter in volts and A = the rating of the meter in amperes Thus, a 5 ampere 100 volt polyphase

meter which is used without current or voltage transformers is equipped with a 1 kw counter $\left(\frac{2\times100\times5}{1000}\right)=1$. If the same meter were used with 2000/100 voltage transformers and 50/5 current transformers, a 200 kw register would be furnished. $\left(\frac{2000\times50\times2}{1000}=200\right)$ Therefore, if the meter with the one kw counter were used with 2000/100 voltage transformers and 50/5 current transformers, the dial reading would have to be multiplied by 200, which is the product of the current and voltage transformer ratios. The rule for determining a multiplier or dial constant can be expressed by the following formula:—

New dial constant $= K \times$ *old dial constant*,

Where K = Product of second set of transformer ratios divided by product of first set of transformer ratios

This equation, applied to the example given in the above question, gives a new dial constant of 100

$$K = \frac{20\times300}{60\times1} = 100$$

New constant = K × 10 = 100 × 10 = 1000. The above equation applies to a singlephase or polyphase meter. A. R. R.

2004—CURRENT TRANSFORMERS IN SERIES —Is it possible to operate current transformers in series? If so, what special merits will be derived from such a connection P. J. V. S. (WIS.)

Since the load on a current transformer is connected in series, an increase in load means that more voltage will be required from the current transformer. This calls for increased flux in the iron and consequently increased exciting current; and since it is the exciting current which causes errors in current transformers, the greater the exciting current the greater the error. There is, therefore, an advantage in using two similar current transformers in series if the secondary load is heavy. J. B. G.

2005—SHELLAC—Is shellac purchased ready mixed as good for electrical use as that made in the home shop? At what temperature should an armature be baked after dipping? What is the safe temperature to dry out moisture and water after an armature is wound, so as not to destroy insulation? F. H. (W. VA.)

There is no reason why the ready mixed shellac varnish is not as good for electrical use as that made in the home shop. In fact, at the present time, it is so difficult to get alcohol of the proper degree of purity that it is probably better to use a ready mixed shellac varnish than to try to buy the alcohol and gum shellac in small quantities, as would be necessary in a small shop. This is because varnish makers have enough demand for the alcohol to justify the trouble necessary in obtaining the proper alcohol for making shellac. Owing to the high cost of shellac gum, many varnish makers manufacture shellac substitutes, but if the pure shellac is requested, they will supply it, at a higher price than the substitute. The proper temperature to dry out insulation is slightly above the boiling point of water. This is also a good temperature to use for baking an armature after dipping. The temperature should range from 100 to 110 degrees C. L. E. F.

2006—MOTOR-GENERATOR FOR RAILWAY WORK—Why is an impedance coil connected in series with the commutating-pole shunt resistance on a 500 kw, 600 volt, 720 r.p.m. motor-generator used for railway work, as shown in Fig. (a). A. H. K. (CAL.)

In a commutating-pole machine, a small pole is placed between two adjacent main poles for the purpose of setting up a local magnetic flux under which the armature coil is commutated. In order to assist commutation, this local flux must be opposite in direction to the interpolar flux set up by the armature winding itself, and for the best commutating conditions it should vary in proportion to the armature field, that is, to the armature current, except where there is saturation in the armature flux path. To set up this flux in the opposite direction, the magnetomotive-force in the commutating-pole winding obviously must be greater than that of the armature winding and, in order that the flux may vary in direct proportion to the armature field, the

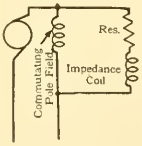


FIG. 2006—(a)

commutating pole is excited by windings connected directly in series with the armature. The commutating pole magnetomotive-force can be considered as made up of two components, one of which neutralizes the armature magnetomotive-force, and the other sets up the actual commutating-pole flux that is useful in generating a voltage of the proper value and direction in the coils undergoing commutation. Now consider, for example, a commutating field winding consisting of 30 turns. Assume that the neutralizing component is 27 turns, and the useful component is 3 turns. If the flux of the commutating field winding were changed by the equivalent of one turn (1/30 or 3.3 percent) the useful component would be changed by 33.3 percent. Either the commutating-pole field winding must be calculated with an extremely small percent of error, if it is to set up a flux of the proper value, or some method of regulating this flux must be used. At first, a plain resistance shunt was used to regulate the current through the winding, but this had its disadvantages in that the shunt and field winding did not properly proportion the current of the varying loads, due to the inductance of the field winding itself, consequently, on machines operating under frequent and sudden changes of load, the result of using such a shunt tended to overbalance the good results for which the commutating winding is used. The advisability of using a different method for regulating the commutating pole flux became quite evident, and an inductive shunt has been used to a great extent in place of the plain resistance shunt. It is obvious that if the proper impedance is used in the shunt, the winding and shunt will properly divide the current while operating under either varying or constant loads. Hence, the commutating pole flux will always have its proper value in the range of operation for which the machine was designed, after the shunt has once been properly regulated. Inductive shunts are still used to some extent, but another method which is used more now, does not require the use of a shunt. In this method, the commutating pole air-gap is changed by the use of steel liners placed between the commutating pole and the frame. This regulates the reluctance of the magnetic path, and hence the flux that crosses the air-gap is of the proper value for good commutation for all loads within the range of operation of the machine, and no other regulation is necessary, thus the use of any shunt whatever is avoided. H. B. W.

2007—SELECTING TURBOGENERATOR UNITS —Under the assumption that the distribution losses of the system are negligible, what would be the best unit to select, a 1500 kv-a, 220 volt turbogenerator supplying current direct to a 220 volt system or a 1500 kv-a, 4600 volt, turbogenerator supplying current to the 220 volt system through a bank of step-down transformers? Can you give me an approximate cost of the two installations; also approximate cost for transformers required with 4600 volt unit. If the 220 volt turbogenerator requires more floor space and is more expensive than the 4600 volt unit, please give reasons why? In both cases assume the same powerfactor for a 1500 kv-a, three-phase, 60 cycle system. J. E. M. (MICH.)

We would advise 2400 volts for a 1500 kv-a, turbo unit. On account of the large currents to be handled by the small number of armature conductors, 220 volts is too low. To build a 220 volt 1500 kv-a unit is almost impossible. Even if built it would not give satisfactory service due to the insulation troubles developed by the excessive mechanical strain caused by the heavy current. A 4600 volt unit is objectionable on account of the thicker insulation required in the unit itself and the transmission lines and transformers. The 220 volt unit would be expensive to build on account of it not being standard practice to build this type of machine and the enormous increase in copper required. The 2400 and 4600 volt units, including the transformers, would undoubtedly occupy more floor space than the 220 volt unit, but the assured continuous service would more than compensate for this extra investment. F. D. N.

2008—CARBON-TETRACHLORIDE FUSE — What is the principle of the carbon-tetrachloride fuse, and how is it constructed? P. N. P. (KENTUCKY)

The carbon-tetrachloride fuse consists of a long glass tube with a metal ferrule at each end. The tube contains a spiral spring, the lower end of which is fastened to the bottom ferrule. The spring is stretched and the upper end fastened to the fuse wire, which in turn is fastened to the upper ferrule. The inside of the tube is filled with carbon-tetrachloride or some other liquid fire extinguisher, completely surrounding the spring and short fuse wire. When an overload comes on the circuit, the fuse wire becomes hot and melts. This releases the stretched spring which contracts towards the bottom ferrule. The arc which is formed at the fusion of the

wire is drawn out longer and longer by the contraction of the spring. In addition, the liquid fire extinguisher is poured onto the arc and aids greatly in its extinction. The glass tube allows the operator to observe the position of the spring, which indicates whether the fuse has been blown or not. The most general use of these fuses is on the primary side of power and potential transformers.. J. D. W.

2009—STARTING SQIRREL-CASE INDUCTION MOTOR—If a standard squirrel-cage motor of, say, 15 hp, three-phase, 60 cycles, 220 volts is connected direct to the main switchboard of a 20 kv-a generating plant, driven by an oil engine through a three-pole knife switch or a three-pole oil switch with time limit overload trip coils only, and without any other starting device, can the motor be successfully started under load by starting the engine and gradually building up normal voltage and frequency as the engine runs up to speed. About what will be the maximum starting torque developed by a motor so connected and about what will be the maximum current per phase relative to the normal full load current? If the motor starts with light load requiring, say, approximately 50 percent of full-load running torque, about what will be the value of current required to start the load and run the motor up to normal speed? M. O. S. (ILL.)

This method of starting can be used, where possible, and will give any value of torque up to almost pull-out torque. Care must be taken, however, to keep the ratio of frequency to voltage as nearly constant as possible, or near that of normal operation, in order that the field strength will vary as little as possible. If these conditions are maintained the operating characteristics as far as current and torque are concerned, will be about the same as under normal condition; so the current required to start under a given torque will be practically the same as that required to develop the same torque under normal running conditions of voltage and frequency. These conditions hold if the voltage and speed are reduced to a very low value at start, something near the full-load slip. If the motor is started with a higher value of voltage and frequency than this, the current for a given starting torque will increase along the same curve as for a corresponding value of slip on the speed torque and speed current curves. For the case given, if the motor starts at 50 percent full-load torque and a starting voltage and frequency of about one-third normal value is used, an ordinary motor will take slightly above full-load current. C. W.K.

2010—HEATING OF ALTERNATOR STATOR CORE—A 150 kw, two-phase, 60 cycle, 36 pole, 2200 volt alternator having 72 coils and 144 slots was recently reconnected nine parallel for 230 volts. When run no load at 220 volts the field takes 40 amperes and stator core heat is noticed within five minutes. When run for two hours with 150 kv-a load and room temperature 34 degrees C, the stator core registers 92 degrees C and the winding only 65 degrees C and the field takes 62 amperes. The voltage began to drop slowly near the end of the test, both exciter and main rheostats having been cut all the way out. The generator is of the revolving field type and the stator coils are each wound with a single wire looped through the slots sixteen turns. Can this trouble be corrected by tearing the core down and repainting the punchings and rewinding? Judging from the method of winding the coils this is the old type of machine. Is it possible the iron may be bad due to ageing and new punchings be necessary? Would not this have to be a 108 slot core for three phase? G. E. D. (PA.)

We have never known of a case where ageing of the iron led to an abnormally high core rise. The high temperature rise may be due to any one or a combination of the following causes:—(1) Loss of insulation between individual sheets of the armature core. (2) Obstruction by dirt, or otherwise, of the ventilating ducts through the armature core. (3) Failure to replace on the rotor the ventilating fan blades, if there are any, after making repairs. In case the trouble is due to (1) the armatures should be torn down and the core plates repainted. For (2) and (3) the remedies are obvious. A balanced three-phase winding could not be made with the present number of slots. If new iron was supplied for a three-phase winding there should be 108 or 216 slots, if the present closed slot design is retained. If open slots are used, a balanced winding can be obtained with any number of slots which is divisible by 27, i. e. 108-135-162, etc. provided all coils per phase are in series. If the groups are to be parallel some of these slot combinations would not be permissible, depending on the number of parallels used. R. A. M.

2011—DESIGNING A SLIP-RING WOUND-ROTOR WINDING—When designing a winding for a slip-ring wound-rotor can the same method be employed as was explained in the Question Box of July, 1918 for a stator winding? I notice the chord factor for rotor windings is unity. Is this always true? G. W. S. (CAL.)

The stator winding is the one that needs most of the designers attention because it must meet a fixed line voltage and do it without overworking or underworking its own copper and magnetic field. If we have given a stator iron core and rotor iron core of a machine of standard proportions, the number of turns in the secondary three-phase winding is practically of no consequence to the efficiency and satisfactory operation of the motor, so long as the slot is filled with a properly insulated winding and the throw is not less than two-thirds pitch. However, it sometimes happens that certain given units are available for use as secondary control; such parts as switches which will limit the current which motor should have at full load; or grids which are better adapted for a given voltage and current. Let. E_2 = Locked voltage per leg of rotor winding; E_1 = Voltage per leg of stator winding (terminal to neutral, if star); $d.\ f.$ = Distribution factor = 0.90 for two phase 0.955 for three phase; $ch.\ f.$ = Chording factor $= \sin\left[\frac{\text{slots spanned}}{\text{slots per pole}} \times 90^\circ\right]$; I = Full load amperes per leg of rotor winding = current per ring divided by 1.73 if delta. Then, given I to start with,

$$E_2 = \frac{746 \times Hp}{3 \times I \times 0.95}.$$

Where R_2 = resistance to permit full-load torque starting on first notch,

$$R_2 = \frac{E_2}{I_2}$$

Solving for transformation ratio between rotor and stator winding,—

$$b = \frac{E_2}{E_1}$$

The required number of series conductors per phase in the rotor must equal,—

$$\frac{b \times N \times d.\ f. \times ch.\ f. \text{ of stator}}{d.\ f. \times ch.\ f. \text{ of rotor}}$$

where N = the number of series conductors per phase. The numberd of series conductors per slot is equal to the series conductors per phase multiplied by the number of phases and divided by the number of slots in the rotor. Rotor windings are generally either wave or lap windings. The wave type is generally full pitch because no saving in copper is made by chording. If it is not full pitch, it is chorded so as to get the short throw on the connection end to prevent the connections from extending too far away from the core. A rotor lap winding should be chorded as a rule to three-fourths or five-sixths of full pitch, because the amount of copper and room saved more than offsets the loss in locked voltage. H. S. S.

2012—FIELD SWITCH AND DISCHARGE RESISTANCE—Please advise the best practice in the use of field switches for direct-current generators, i. e. two and three wire, 125, 250 and 600 volts, turbine, engine or motor driven generators, of commercial sizes. Kindly give me also the reasons for the particular practices in this matter, the generators also to operate single or in parallel with others. The information I desire is, when to use a field switch and discharge resistance and when not to. O. W. C. (D. C.)

We do not believe that field switches for direct-current machines are necessary or even desirable in the great majority of cases. As a matter of fact, the use of field switches with machines operating in parallel introduces a considerable hazard, because the accidental opening of the field switch on one generator would cause practically a dead short-circuit on the other machines. This heavy short circuit current would, of course, flow into the machine having its field circuit open until interrupted by automatic protective devices. In a few special cases, field switches may be applied to advantage, generally when a single generator feeds some single load directly, as for instance, a direct-connected exciter supplying its own generator field. In this case, excitation can be put on or taken off the main alternator through an exciter field switch mounted on the switchboard. In this way, the necessity for carrying the heavy exciter main leads to the switchboard is eliminated, or the more or less expensive remote control solenoid operated circuit breakers are rendered unnecessary. Discharge resistors should be used with every installation of field switches. R. C. S.

2013—TESTING LARGE TURBOGENERATOR—How are the coils tested during the various stages of building of large

turbos? What is the most suitable capacity of testing transformer used for testing windings of large turbos?

N. B. (RHODE ISLAND)

These coils are wound on formers, then insulated in line with the specifications. A test is then made for short-circuits between turns before treatment, and an insulation test is made on the coils before they are wound into the machine. Before cross connections are made, another check is made for short-circuit between turns and after connecting an insulation test is made on the entire winding. A 30 kw testing transformer is most suitable for this work.

L. E. S.

2014—Violet Ray— Kindly give a description of the apparatus necessary for the production of the violet ray?

H. P. W. (IND.)

Ultraviolet radiation is produced in abundance by an arc between nearly any kind of metallic electrodes. Mercury and iron are most used. Since the more useful radiation (of shorter wave lengths) will not pass through glass, windows and lenses of glass cannot be used. Quartz windows and lenses may be used freely since quartz transmits the ultra violet ray. By far the most convenient source of ultraviolet radiation is the commercial quartz mercury arc with automatic control, such as was in common use from 1905 to 1910. This is mounted on an opening in the top of a box provided with a sliding glass side for observation. Eczema is treated by simply inserting the affected member under the arc, 6 to 15 inches from the bulb. When higher intensities are desired, an image of the arc is thrown on the affected part by means of a large quartz lens of about 2.5 inches diameter and 6 inches focal length. Highly concentrated radiation for the treatment of lupus is obtained by focusing an image of an iron arc directly on the part to be treated. Rods of ordinary iron, 1/4 to 1/2 inch in diameter are used as electrodes. The arc is enclosed to protect the operator. A side tube about three inches in diameter and two feet long carries the quartz focusing lens in its center and has the iron arc at one end and the part to be treated at the other.

P. G. N.

2015—Secondary Current of Induction Motor—When is the secondary current of a variable-speed, phase-wound induction motor largest when (a) driving a fan; (b) driving a centrifugal pump; (c) driving a load requiring constant torque such as an air compressor. Assume motors which have (4) percent slip on full load with secondary rings short-circuited. Of course, the above question is for running conditions.

H. H. (OHIO)

The secondary current does not depend on the kind of load but on the amount of load the motor is carrying. The secondary current varies almost in direct proportion to the load in any particular motor, but the values of currents in different motors do not follow any rule, as they are varied to suit manufacturing conditions. If you mean to inquire at what running speed the secondary current will be greatest, this will depend altogether on the relation between the horse-power and the speed of the driven load. The power input to a centrifugal pump or fan varies approximately with the cube of the speed. Increasing the resistance in the secondary decreases the speed of the induction motor and when driving a fan or centrifugal pump the load will drop off rapidly with the decrease in speed. As the decrease in load will lend to decrease the percent slip with a given resistance, it is apparent that two conflicting tendencies are introduced which will to a certain extent nullify one another. That is, the decrease in the speed that will be obtained with a given resistance is much less when driving a fan than when driving a constant torque load. In either case however, the horse-power will be less at the lower speed. The current in the secondary will vary directly with the torque up to about 50 percent overload; if the torque decreases with the speed, the secondary current will also decrease with the speed. But if the torque is constant regardless of speed then the secondary current will be constant at all speeds within the range which can be produced by inserting resistance. The above statements are independent of the amount of resistance inserted in the secondary.

C. R. R.

2016—Drying Out a Vertical Motor—We have a 550 hp, 2200 volt, three-phase vertical motor, with wound rotor for driving a large water pump. The motor is seldom used, therefore moisture collected in the windings and it was necessary to dry the machine. We dried this motor with 220 volts or 60 amperes in the stator windings by short-circuiting the rotor winding on the collector rings. After drying the windings in the above manner for two weeks we tested the insulation and it showed a resistance of four megohms to ground. In running the motor again we found that the air-gap is not even all around and the collector rings are not running true. The motor draws more current than usual, in fact it is over-loaded. Is it possible that the shaft is sprung due to uneven pull on the core? Or is the shaft warped due to uneven heating on part of the winding? If so please explain how we can remedy it?

M. T. C. (HAWAIAN ISLANDS)

This shaft could not be sprung by uneven pull in the air-gap, nor by uneven heating. The shaft could only be sprung by some outside mechanical force. This should be checked with gauges on the shaft and gauges in the air-gap when the rotor is in different positions. The uneven air-gap could be caused by worn bearings and this should be checked. The collector ring insulation may have warped and thrown the rings out of true. If the shaft is not sprung, the rings should be trued up.

C. W. K.

2017—Efficiency of Rebuilt Motors—What efficiency is to be expected from rebuilt motors, having been through a fire? The copper was not melted in any stator or rotor coils. They range in size from 15 to 100 hp. End bells, shafts, rotors and stators after being carefully checked, show little or no warping. By using factory data on all replacements, is it possible to obtain nearly as good results as original? What bad effect has heat on stator laminations?

R. P. M. (UTAH)

There are two things in the primary core which are affected by heat, the iron itself and the japan on the punchings. The iron itself will be annealed or even burnt, depending on how hot the motor was and how long it lasted. The right amount of heat applied long enough will be beneficial in decreasing the iron loss, but too much heat will oxidize the iron thus leaving less real iron to carry the flux, causing the core loss to be greater. The japan on the punchings will be burnt and may or may not allow the punchings to touch and increase the eddy current losses in the iron. About the only way to tell whether these motors should be rewound is to take the one which looks the worst and rewind it, taking the losses at no load and comparing them with the tests of the motor when new. If this shows very little increase it would be all right to rewind all the motors.

C. W. K.

2018—Transmission Line—It is proposed to run a power line 34 kilometers to supply 500 kilowatts at 80 percent power-factor (lagging). We generate at 600 volts, three-phrase 60 cycles ungrounded neutral and proposed to step up to 22000 volts and step down again to 600 volts at the other end for distributing to squirrel-cage motors driving centrifugal pumps. The transmission line is to be No. 2 B. & S. copper wire strung in the form of an equilateral triangle with three foot sides on galvanized iron posts 35 ft. high, and set 80 meters apart and a ground line of No. 12 copper. How often would it be necessary to have anchor posts? What would be the power loss at full load? What should be the overall efficiency of the system (Ratio of power put in transformer at sending end, to power available at low-tension side of transformer at receiving end). There is a group of three telegraph lines running parallel with the proposed power route for about 24 kilometers. How far would we have to keep away from these to avoid inductive interferences? Would 50 ft. be sufficient clearance and would it be necessary to transpose the power lines?

E. M. O. (MEXICO)

For normal conditions it will be necessary to have one anchor post per mile; however, you may need more than this, depending upon the factors which influence their use. Our experience shows that No. 12 copper wire may give trouble, if used as a ground line on this system. It would be better to use a No. 6 copper clad ground wire. The voltage at the receiver end will be 19000 volts at full load. This is based on the assumption that the receiver transformer will be rated at 670 to 700 kv-a, 22000-600 volts. This arrangement will give a receiver voltage of 650 volts at no load, and 550 volts at full-load. The powerloss at full-load will be 34 kw, and the overall efficiency will be 93.5 percent. It will not be necessary for you to transpose the power lines. The clearance of fifty feet will be sufficient for normal conditions on the power system. If the system is not grounded, you need not anticipate trouble from inductive interference in the telegraph lines in case of a ground. For a grounded neutral system, inductive interference may occur in case of a ground on the transmission system.

This interference is only of a momentary nature, as it ceases when the circuit breaker opens. An article by Mr. A. W. Copley in the JOURNAL for Aug. 1920 gives important facts on the subject of inductive interference. C. M. H.

2019—MOTOR SPECIFICATIONS—The following is a copy of motor specifications we have written on some direct-current machines: 35 hp motors, direct-current, 230 volts, adjustable speed, shunt wound, interpole, 400 to 1600 r. p. m., constant service. Temperature limits 40 degrees C. and 45 degrees C. commutator, at full load. Have we a right, under these specifications, to expect full load of 35 hp at 40 degrees C. temperature rise at any speed between 400 r. p. m. and 1600 r. p. m. inclusive? J. M. D. (PA.)

This specification would be interpreted to mean that the temperature rise should not exceed 40 degrees C. for a 35 hp load at any speed from 400 to 1600 r. p. m. The specification should read "Temperature rise not to exceed 40 degrees C." instead of "Temperature limits 40 degrees C." R. W. O.

2020—SOLDERED JOINT—Can you give me any general data regarding the allowable current density across a soldered joint, as for example, connecting leads soldered to field coils of a turbogenerator. In other words, in a case where all the current must pass directly across the soldered joint from copper to copper. N. G. H. (ARIZ.)

It is the usual practice, when the members to be soldered have a large cross-section, to consider the current carrying capacity of the soldered union to be equal to that of the adjacent solid material. This practice is justified by the fact that the intervening film of solder is very thin. Where strap sections, having a thickness of 1/16 inch or less, are soldered, the film thickness is an appreciable factor in lowering the current carrying capacity, so that it is customary to rate the joint at one-half the current carrying capacity of the solid copper. O. H. E.

2021—STARTING SYNCHRONOUS MOTORS—Kindly advise me of the various methods of starting synchronous motors. In starting a 220 volt, synchronous motor with field circuit open and using a 110 volt tap on the starting autotransformer, does the motor reach full synchronous speed or is there a slip? Why is it advisable to start a synchronous motor by applying a reduced voltage to the stator and then applying a weak field before applying full voltage to the stator? Does it make any difference whether the field is applied before the machine has reached full speed or after? M. M. R. (OHIO)

Any synchronous motor will start itself as an induction motor when alternating current is introduced into its armature winding. Some motors will start more efficiently in this way than others, depending upon the construction of the rotating part. With laminated field poles there is very little chance for the armature current to induce currents in the revolving part and relatively little torque will be developed. A rotor with solid field poles permits better circulation of the induced currents and hence, will develop considerably more torque. A rotor provided with a cage winding similar to the cage winding of an induction motor will develop a still greater torque. All synchronous motors should be started with the field short-circuited through the field rheostat set in the running position. In case the machine is started with the field open, there is a high voltage induced in the field coils. In a great many cases this voltage is high enough to be dangerous to the operator, since it appears at the field switch, and may cause a break down in the field insulation, unless special precautions are taken at the instant of starting and at low speed. There is usually a slight gain in the starting torque for a given value of line current when the field is open circuited. The maximum speed which the machine will reach as an induction motor is higher when the field is closed during starting, consequently its ability to pull into step is greater when the field is excited. This gain is usually of more importance than the small increase in initial starting torque obtained by leaving the field open. When the motor reaches full speed on the half voltage the fields should be excited before switching the machine to full voltage. The full speed on half voltage may be synchronous speed; however, generally it is slightly less, due to the slip which may occur before the rotor is locked in step by the exciting current. The field should be excited when the motor has reached full speed at half voltage, which can be a little less than synchronous speed, and before switching the motor to full voltage. The field current will not only lock the rotor in step but if it is not running at synchronous speed it will tend to pull it into step and hold it there. Provision must be made for starting at a reduced voltage in order to keep the armature current within a reasonable value. M. M. B.

2022—FLASH OVER OF SLIP RING MOTOR—What would cause a slip ring induction motor to flash over across the collector rings and brushholders. I suppose an open circuit in secondary would cause that, but in this case there is no open circuit, the attendant in charge of the motor claims that motor flashed over before, and when he tried to start it again it started right off. I was sent on the job and the only thing I found was that one phase of the secondary was left open when the equipment was installed. I closed it by connecting D, E, and F to a common point to form a star connection on the outside of resistor grid and had no better result. The motor flashed over just the same. The motor was left idle for several days and was tried again and this time started without flashing over. The machine in question is a 206 hp, three-phase, 60 cycle, 2200 volts, 52 amperes per terminal, 575 r. p. m., induction motor. F. A. B. (PA.)

The only explanation we can see is that some times the rotor stops with some dirt or other foreign substance under a brush. Then when it is started the highest voltage is applied across this poor contact, which burns up and causes a flash which may reach to the next ring and cause a short-circuit. On starting again it will start O. K. if the first flash burnt the obstacle away sufficiently to give a fairly good contact. See that the collector rings and the insulation between rings are kept clean. C. W. K.

2023—MOTOR-GENERATOR SET—We have a motor-generator set which seems to be over compounded. The name-plate data of the generator is:—37.5 kw, 250 volts, 150 amps. 850 r. p. m. The name-plate data of the induction motor is as follows:—50 hp, two-phase, 200 volts, 120 amps per terminal, full load speed 850 r. p. m. This machine is running at 890 to 895 r. p. m. instead of 850 r. p. m. receiving power from a 220 to 230 volt circuit supplied from 4400/230 volts transformer. I have put all kinds of shunt resistances in between the series fields trying to balance the voltage. The direct-current voltage pumps from 220 to 245 volts on a 50 ampere load. No matter how much resistance we insert in the series field, the voltage will not balance. We checked up the wiring and it seems to be right. Connecting the generator long or short shunt will not make any difference. When a heavy load is applied the voltage increases to such an extent as to burn out 230 volt lamps. Is this trouble due to the machine running above rated speed? Would annealing the pole pieces do any good? M. J. W. (PA.)

From your data giving the terminal voltages at different loads it appears that your trouble is due to the machine being over compounded. Your data does not give the voltage regulation for different values of shunt resistance, but as the resistance of the shunt, which is connected in parallel with the series field, is decreased and more and more current shunted out of the series field, the increase in voltage as the machine is loaded becomes less and less until the point is reached where practically all of the current is shunted out of the series fields, when the terminal voltage of the machine will fall off as the load is thrown on. Check your series field shunt connection to see if it is in parallel with the series field—short-circuit the series shunt and load the machine—the terminal voltage should fall off. Your trouble is not due to the machine running above rated speed nor would annealing the pole pieces have any effect. Examine the original shunt furnished with the machine and see that it is making good contact—if it is, try shifting the brushes. Shifting the brushes in the direction of rotation on a generator reduces the compounding; shifting them in a direction against rotation increases the compounding. Care must be taken, however, that the brushes are not shifted so far that commutation is impaired. If the old shunt has been broken or destroyed a new one can be made. Data can be obtained to have the machine shunted to give any degree of compounding by substituting a rheostat in series with an ammeter for the series shunt. By varying the rheostat until the correct degree of compounding is obtained and reading the shunted current a shunt can be made to duplicate that compounding. H. S.

2024—CEMENTING FLEXIBLE INSULATION —What can be used to cement the gauze back on the insulation used in motor slots which will leave the insulation flexible? I have used shellac but this is too brittle.
G. W. S. (CALIF.)

The shellac may be made flexible by adding a little castor oil and stirring until it is dissolved. The amount of oil to use can be determined by trial, but probably will be about 10 or 15 percent.
L. E. F.

2025—COMMUTATOR TROUBLES—I have a 75 hp, direct-current, 220 volt shunt wound commutating-pole motor driving a 50 kw alternator which has been in operation since last October. The commutator, instead of coloring up to a chocolate color all around, will be streaked with a bright place about one-half an inch wide and then again it will vary to different widths that will go around the commutator only about half way. The commutator is smooth and the brushholders are all in line, about 1/8 in. away from the commutator. There is no sparkling at any of the brushes. I put in four new brushes where the trouble was, thinking there was a hard place in the old brushes but it did no good. Little specks of copper collected on the frame of the machine. I cleaned the slots of the commutator and what seemed to be mica dust came out of them. After that the commutator took on a good color but did not stay that way long. Kindly inform me if there is anything that I could do to make the commutator take a uniform color all around.
H. A. B. (MASS.)

At the positive brushes on a motor, the current passing from the brush to the commutator carries along minute particles of carbon. These particles tend to give to the commutator a dark glossy finish. At the negative brushes, the current passing from the commutator to the brushes tends to carry along minute particles of copper. The removal of these particles tends to give to the commutator a bright, raw appearance. For some unknown reason, at places on the commutator the effect of the latter action is greater than that of the former. The fact that a change of brushes did not help indicates that the trouble is not caused by a defect of the brushes. If the trouble were caused by a defect of the brushes or brushholder rigging, the bright places should extend entirely around the commutator. As this condition does not exist, the cause of the bright places is probably something about the armature. From the data given it is impossible to tell definitely what is wrong. The most probable cause of the bright place is that the slots between the commutator bars are not thoroughly cleaned out over the whole width of the mica. Possibly small pieces of mica extend up at each side of the slot and the brush rides on these pieces of mica, causing a slight sparking underneath the brush. This sparking would then eat away the commutator causing a bright place about where the mica projects. Frequently, to avoid any possibility of all mica not being cleaned out, the slot made in undercutting is made even wider than the thickness of the mica.
S. H.

2026—THERMOPHONE—Can you give me any information regarding the thermophone? Can this instrument be used in connection with an earphone?
W. W. K. (MASS.)

The thermophone is an instrument for measuring temperature, particularly the temperature of a distant or inaccessible place. It is used for the purpose of determining temperature of the water of lakes and ponds at various depths. Thermophones are embedded in the masonry, during the construction of dams in order to determine the thermal changes in the large masses of masonry. The thermophone consists essentially of two coils of many turns of fine wire of two metals having different temperatures coefficients of electrical resistance, connected in circuit with batteries and a galvanometer. The wires of the coils are of such size and length that a small change in temperature causes a measurable change in electrical resistance, which is indicated by a galvanometer or detected by a telephone by moving the pointer of a Wheatstone bridge until the silent point is reached. The sensitive coils are constructed of copper and nickel silver wire, and are enclosed in a brass tube 1/2 in. in diameter and 8 in. long. The resistance of the sensitive coils must be kept low enough to get sufficient sensitiveness when using an ordinary telephone and it must be kept high enough to avoid the error caused by the heating of the wires by the battery currents. Dealers selling supplies for civil engineers should be able to procure thermophones for you.
M. M. B.

2027—EFFECTIVE CORE AREA—On page 189 of Dudley's "Connecting Induction Motors", he shows how to find the flux capacity of the core of an induction motor. The motor I have in mind has several rivets through the core of the punchings. Does this construction reduce the effective core area or do the rivets carry flux the same as the punchings?
E. L. C. (OHIO)

In this type of motor the average value of the largest and smallest diameters may be used as the outside diameter. A rivet is not figured as carrying flux but the iron below the rivet is figured as being effective.
C. W. K.

2028—CAPACITY SUSCEPTANCE—I would be pleased to know the meaning and value of the term and how it is evaluated.
H. C. O. (NEW ZEALAND)

In a simple condenser, the charging current leads the voltage drop by 90 degrees. The charging current is numerically equal to the product of the voltage drop times the factor $2 \pi f C$ which is called the capacity susceptance; or $I_c = E_c 2 \pi f C$, where $f =$ frequency, $C =$ Capacity of condenser in farads and capacity susceptance $= 2 \pi f c = \frac{I_c}{E}$

Capacity susceptance is expressed in ohms or microhms. A capacity of one microfarod at 60 cycles has a capacity susceptance of 377 microhms or $377 \times \frac{1}{10^6}$ ohms.
M. M. B.

2029—MAGNETIC BRAKES—Why are the coils in alternating-current magnetic brakes wound in two equal sections?
G. W. S. (CAL.)

This is more a manufacturing reason and a conservation of winding space than anything else, although winding a coil in two sections with an insulating washer between reduces the voltage between turns to half the voltage of a coil wound in one section. If the coil were wound in one section, however, it would be necessary to bring one lead out along the side of the winding, whereas in winding in two sections the start of one-half is connected through the insulating washer to the start of the second half and the two are wound in opposite directions to form a continuous winding. This brings both leads out on top and facilitates the attaching of terminals or other external connections to the best advantage. This is true in practically all alternating-current magnet coils where the copper section is comparatively large and the coils wound on nonautomatic machines and does not apply to brake magnets alone.
H. C. J.

2030—NUMBERS ON ARMATURE SHAFT—I have found a series of numbers stamped on one end of the shaft of motors and generators, and I have been told that these indicate, to anyone who can read them, all the details of the winding, such as size of wire, number of turns, pitch, etc. Is this true? If so, please tell me where I can get a copy of the code which explains them.
G. D. (SASK.)

The statement that the number stamped on the end of the rotor shaft indicates all the details of the winding is in one sense true, but in another sense it is untrue. Before a motor of the industrial size is shipped, a serial number is assigned to the rotor and is stamped on the end of the shaft. This number is recorded together with a note giving a reference to the plans and specifications used in building the motor. Therefore, if the serial number is known, the factory records can be used to determine all details of the motor construction. In this sense the statement is true. In the sense that the numbers form part of a code which gives winding details, the statement is totally incorrect.
S. H.

2031—STARTING FREQUENCY CHANGER SETS—Kindly give me correct information for starting up a 440 volt, 60 to 120 cycle induction type frequency changer set. I presume the proper method is to run the changer as a motor first by short-circuiting the collector rings, to see in which direction it will run, then try out the motor to see if it runs in the opposite direction.
J. P. (IND.)

The presumption is correct. Start the slip ring machine alone—by short-circuiting the rings and connecting to the line, and observe the direction of rotation. Then see that the driving motor drives the slip ring machine in the opposite direction, with secondary open.
H. S. S.

CORRECTION

In the JOURNAL for July 1921, p. 294 the cuts for Figs. 4 and 5 should be interchanged.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

AUGUST 1921

Tinning Malleable Iron Bearing Shells

Many railway motors have malleable iron shells lined with babbitt on both armature and axle bearings. This condition applies more generally to the older type of railway motors, as in the more modern motors, bronze armature bearings lined with babbitt and bronze axle bearings tinned have been largely adopted as standard. This change has been brought about by the campaign for the light weight motors, as the bronze bearing can be made with a thinner shell, thus smaller size, than a malleable iron bearing shell made for the same size shaft or axle. In the case of bearings made for an axle diameter less than standard, which necessarily means a heavier shell, malleable iron bearings are quite often used on the modern motors.

LOOSE BABBITT LINING

The common practice in connection with all iron bearing shells is to provide the babbitt seat of the shell with anchors to hold the babbitt in place. These anchors usually take the form of cored holes enlarged at the bottom, and plain or dovetailed cored grooves. In some cases, these anchors in the form of holes or groves, are machined in the shell. A few operators have drilled anchor holes through the shells and countersunk the outer ends of the hole, which is reported to prevent babbitt from breaking away from the shell.

It is an accepted fact that this type of bearing gives more or less trouble in service, due to the babbitt becoming loose and breaking away from the shell. This is largely due to some of the following reasons:

1—Inferior grade of babbitt.
2—Incorrect heating and pouring temperature of the metal.
3—Mandrels and shells not properly heated.
4—Lack of skill in babbitting.

Bearings that have been made with all of the above conditions kept just right have been known to last a number of years in service without giving any trouble. On the other hand, where the conditions of babbitting are questionable, and operating conditions severe, the babbitt lining of bearings of this type soon pounds loose, and with oil working in between the babbitt, and the iron shell they rapidly deteriorate and must be replaced.

TINNING MALLEABLE IRON SHELLS

As very little trouble is experienced with the babbitt lining breaking away from properly tinned and babbitted bronze bearing shells, a method of tinning malleable iron shells has been worked up, which has all the indications of being very satisfactory in service. This method is based upon and is similar to a method used successfully for the past several years in tinning wrought iron pipe shells which are lined with babbitt metal, and used for bearings on industrial motors. The equipment and general arrangement of dipping tanks necessary to do this work are shown in Fig. 1. This method also applies to cast steel bearing shells.

CAST IRON SHELLS

Cast iron can be tinned by this method by reducing the temperature of the tinning alloy to a point where the hot metal will just run off the shell when taken from the tinning pot. When cast iron shells are properly tinned, they will have a nice bright finish and look good, but in babbitting, the metal will not stick to the tinned surface very tight. It will give a much better job than when not tinned at all, but not nearly so good a job as obtained on malleable iron or steel shells.

CLEANING AND PICKLING

If the bearing had been in service, remove the old babbitt, oil and dirt by burning. Allow the bearing to cool after cleaning and then pickle the shell for about 10 to 15 minutes in a solution made up of one part sulphuric acid and ten parts of water. If this solution is heated, the time of pickling can be cut down to five minutes. Remove the shell from the pickling bath and rinse in clean water, preferably running water; otherwise, the water will soon become a weak solution of sulphuric acid.

FLUXING AND TINNING

After the shells have been pickled, they are dipped (either wet or dry) in a flux of zinc chloride. This flux is a saturated solution of zinc in hydrochloric (commonly known as muriatic) acid, which is made by adding zinc to the acid until it will not dissolve any more. After being allowed to drain until the surplus flux has run off, but while still wet, dip in the tinning alloy which should be half and half solder. The temperature of the tinning alloy should be maintained between 410 and 440 degrees C. (770 to 824 degrees F.) and the shell, in tinning, should be brought approximately to the same temperature .Remove the shell from the pot and brush with a stiff brush to remove excess solder.

BABBITTING

The tinned shells should be babbitted immediately after the tinning operation. When this is done, no additional preheating of the shell is required. If the shell is not babbitted immediately after tinning, it should be dipped in the tinning pot again just before babbitting. For details in connection with babbitting, see R. O. D. for Oct. 1916. The most important points to be given special attention while doing this work are as follows:—

1—Tin bearings in half and half solder, and not in the regular babbitt metal.
2—Temperature of tinning alloy 410 to 440 degrees C.
3—Temperature of mandrel 100 to 150 degrees C.

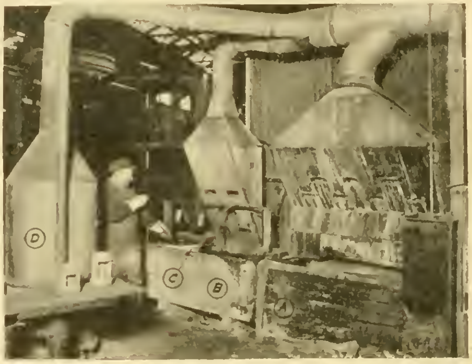


FIG 1—*A*—SULPHURIC ACID PICKLING SOLUTION; *B*—CLEAN RUNNING WATER; *C*—ZINC CHLORIDE SOLUTION; *D*—TINNING POT WITH SHIELD

4—Do not use any wet mud to close up windows, etc,. as this tends to chill the bearing.
5—Pouring temperature of babbitt 460 to 482 degrees C.

PRECAUTIONS

In connection with doing this work, the following points should be carefully noted:—

1—The workman should stand aside when dipping the wet shell in the tinning solution, to avoid being burned by splashing metal.
2—A metal shield should be placed around the tinning pot to protect the workman.
3—Shells that are not well tinned should be placed in the pickling bath till clean and retinned.
4—Do not brush or attempt to swab the inside of bearing shells after tinning, as a slight trace of grease will keep the babbitt from sticking to the shell.
5—Exhaust hoods or a canopy should be provided over the acid bath, to carry off the poisonous fumes.
6—To keep the babbitt from sticking to the window and the outside of the shell, coat these parts with a red clay wash.
7—Clean out the pickling tank occasionally. This will depend upon the regularity of the work. It the tank is used continuously, it should be cleaned out every two weeks.

J. S. DEAN

THE ELECTRIC JOURNAL

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The Association of Iron and Steel Electrical Engineers

ERNEST S. JEFFERIES

President, A. I. & S. E. E.

When one carefully surveys the growth of the iron and steel industry, and analyzes the many factors which have contributed to its phenomenal growth, he must be impressed by the important place which electricity has taken. Probably all industries have been affected through the rapid growth and development of the electrical industry, and the extensive application which is following has found a fertile field in the steel industry. We are indebted to those whose research has contributed to this rapid development.

The application of electric motors to steel mill drives, from the smallest auxiliaries to the main rolls, has progressed until motor drive is practically taken for granted in all new installations and is gradually replacing other forms in the older plants. One of the interesting features of this development is the increasing use of automatic control, which relieves the operator of any responsibility in obtaining proper sequence of operations, thereby permitting more rapid and smoother operation.

Another interesting development is shown in the increasing use of electricity for producing heat. Applications of electric furnaces are increasing rapidly and results are being produced which in many cases are so far superior to those obtainable by any other method as to make the question of cost of secondary consideration. No less important are the smaller applications, such as furnaces for heat treatment of steels, melting babbitt, etc., where the absolute and automatic temperature control, quick results, and freedom from deleterious gases are of prime importance.

ERNEST S. JEFFERIES
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In the past, it was not necessary that the steel mill organizations carry an electrical engineering staff, but due to the above developments, each year it has become a greater necessity that a competent electrical engineer be part of the steel mill organization. It is now necessary to carry a well organized electrical department to engineer the new developments, to design, install and operate the ever increasing variety of electrical appliances. With such an organization back of him, the electrical engineer of today has a responsibility intrusted to him which should be zealously guarded, for the interest and thought he gives this trust will determine what the future will bring forth. If the proper time is given to thoroughness in analyzing electrical needs of his plant today, the conditions existing tomorrow will place his department and himself foremost in the plant engineering work. In the last few years we have seen a greater number of men advanced from the electrical department to still more responsible positions than before, and it should be the daily thought of every member of the Association of Iron & Steel Electrical Engineers so to apply himself to the need of the day that he will be the man to be promoted.

There is but one engineering society today devoting its entire work to the iron and steel industry. Holding this position, the Association of Iron & Steel Electrical Engineers is laying out its work so that its papers and meetings will be of interest to the managers, mechanical and electrical engineers, as well as the maintenance and operating departments. It is gratifying to note an ever increasing number of steel mill officials in our membership, and their interest and attendance at our meetings. Our purpose is to cover steel mill problems so thoroughly as to make unnecessary the existence of any other engineering society devoting its entire time to this subject.

The Function and Limitations of Insulation

B. G. LAMME
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TO THE uninitiated, an electrical machine is a source of wonder—a mystery. What are apparently inert wires, attached to a mass of metal, produce rotation through the action of invisible forces. Tremendous turning effort results from an invisible something called magnetism, which has some relation to a multiplicity of wires arranged in some peculiar manner to form what are called armature and field windings.

To the initiated, the invisible forces of magnetism producing rotation are not a source of wonder, usually because of familiarity with the actions taking place and a knowledge of certain fundamental laws. However, to those who know most about the actions of such electrical machines, there is still one source of increasing wonder in such apparatus, and this lies in what is called the "insulation." Here is something that has little or nothing to do with the real activities of the apparatus—its functions seem to be mostly of a negative sort—and yet it is one of the absolutely necessary structural components of the electrical machine. It serves simply as a barrier to keep the electrical current from straying from certain prescribed paths. This looks simple enough. The wonder does not lie in the function of the insulation as much as in the material itself, for structurally it is made up of about as unmechanical components as can be found. This fact is not due to ignorance or bad judgment of the designers of such apparatus, but lies in the very nature of insulating materials themselves.

Fundamentally, insulating materials are non-conductors—that goes without saying. Now, it so happens that metals, or materials of a metallic nature, are fairly good conductors of electricity and, therefore, metallic materials are forbidden as insulations. On the other hand, in the class of proper insulations are found such materials as varnishes, gums, waxes, oils, artificial fibrous materials, such as papers, cloths and so-called fibers, many of which are in themselves merely mechanical separators rather than insulators. Also there are a few mineral insulators such as asbestos, mica, etc. and various porcelains, lavas and similar materials, many of which in their usable state represent artificial products. Many of the fibrous materials, including asbestos, must be impregnated, or filled, with gums, oils, etc., before they become satisfactory insulators. Looking over the whole list, it seems as if almost anything which is bad from a mechanical standpoint, is in the class of insulators.

To make the situation worse, insulation, being principally a barrier to confine the electrical current, must in many cases be applied in such a way that more or less flexibility is required in its application and use. This is especially true in electrical machinery. The insulation, being a covering material in many cases, is naturally more or less exposed, whereas, from its own mechanical nature it should be well protected. Moreover it is subjected to all kinds of heating and cooling, sometimes of a rapid nature, tending to produce cracks and flaws in the material itself, or in some of its elements, which may prove more or less fatal to its insulating qualities.

Back of all this lies the fact that in spite of the years of effort which have been expended on insulating materials, we know as yet practically nothing about their real nature and characteristics. In fact, we do not even know why some materials are insulators and others are not. We simply have at hand certain facts based upon experience, and the art of insulation as it stands today is simply built up on such facts. In laboratory and shop tests, two insulating materials may show up equally well in every way, as far as can be determined, and yet, under similar operating conditions, one may deteriorate rapidly, while the other may remain as good as new. Why? Nobody knows. To repeat, in most cases, all we have is experience and a very limited range of experience at that, due to the fact that, for safety, we have had to keep closely to known methods and materials. If it takes from one to five years of operation to determine the commercial durability of certain insulating materials, and combinations of materials, naturally, the designers dare not take undue risks with new insulations or new methods of using them for, if a material should prove defective after a couple of years, the manufacturer might have an avalanche of trouble on his hands.

Nevertheless, it must be understood that the insulating art never has been, in any way, at a standstill. A vast amount of research and experiment has been carried on by the electrical manufacturers, almost since the beginning of the electrical art, to determine the fundamental characteristics of insulating materials; for the whole success of electrical apparatus is dependent upon such materials.

A manufacturer builds up a certain method of insulating, based upon long experience. The results prove satisfactory but, during many years of practice, little changes creep in, none of them apparently of more than very minor importance, and each one apparently a step in the direction of better results. In some cases the changes may be so small that it is difficult even to perceive them. However, after a while, something goes wrong, the results apparently are not as good as formerly, and the puzzle is then to determine just what has happened. Each minor change is gone over in detail. Eventually the trouble is overcome, but it must be admitted that in some case the real cause is seen only dimly.

This is not a criticism of the designers or research men, but is simply intended to show that, in

insulations, we are dealing, to a very large extent, with the unknown, and that success in the art of insulation is built up largely upon practical experience. From this viewpoint the motto of the designer well could be that "All insulations are guilty until proved innocent."

Considering the difficulties of the problem, it is astounding, to those well versed in the art, that such remarkably good practical results have been obtained and maintained. Advances are being made in the art of insulation and they have been made continuously since the earliest days. With each step forward there have been mistakes, until experience has been obtained; and with the remedy of such mistakes, there has been growth through new knowledge of the subject. Increasing knowledge of the real nature and the real weaknesses of insulating materials on the part of the users of electrical apparatus has been of vast help in this problem. With such knowledge comes appreciation of the limitations, with consequent better care and maintenance. This is a subject "where ignorance is bliss" and where those who know the least about it can make the biggest promises. But the writer fully believes, and has believed for years, that the more the user of electrical apparatus knows about the nature and weaknesses of all insulating materials, the better he is prepared to protect this weakest part of all electrical apparatus.

Electrical Developments in the Iron and Steel Industry

R. B. GERHARDT
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Director, Assoc. Iron & Steel Electrical Engineers

ELECTRICAL development in the iron and steel industry during the past year has been more or less restricted to smaller items which entailed light expenditures and affected a maximum of economy, due to the greatly depressed business conditions. However, quite a few electric main mill drive equipments have been built or put into operation. In this country the replacement of steam engines on the Lackawanna rail mill and the Steelton blooming mill of the Bethlehem Steel Corporation by electric reversing motor drives were noteworthy events. Two reversing drives, one a double and the other a single unit motor, were shipped to India for the Tata Iron & Steel Company. A total of thirty-six additional mill motor drives ranging in size from 5750 down to 300 horsepower were built or completed during the past year by American manufacturers, and six of these went to foreign countries. Thirteen of the thirty-six were variable speed alternating-current equipments.

An item of considerable interest in connection with electrical main roll drives has been the rearrangement of control, making possible a reduction in the operating force on these mills. Blooming mills are now being operated with two instead of three men in the pulpit, and as many as two operators have been displaced on mills like a reversing universal plate mill.

For the steel plant power house, the gas engine is still a prime mover to be seriously considered, as thermal efficiencies equal or better than those of modern steam units are easily obtainable, and the present development makes it possible to obtain in a single unit a capacity of 4000 kw, which is considerably more than that obtained with the older units. It has also been successfully demonstrated that a gas engine installation can be operated from a single furnace in blast by making use of a gas holder of moderate size and certain automatic regulating valves in connection with a gasometer for its manipulation.

An investigation of the possibilities of interconnection between the steel mills and the large central stations reveals the fact that in most of the larger steel plants 25 cycles is the standard frequency whereas central station tendency is toward 60 cycles. For tying together such systems, frequency changers up to a capacity of 7000 kv-a are being built. Such a set will shortly tie the 25 cycle plant of the Tennessee Coal, Iron & Railroad Company with the 60 cycle system of the Alabama Power Company.

The use of electrical energy as a heating agent is rapidly increasing in the steel plant. Electrically heated tin pots, babbitt pots, drying ovens, ovens for heat treating and enameling are some of the principal applications, while special work is being done on the development of equipment for electrical heating of steels for the manufacture of bolts, rivets and spikes.

An event of considerable interest in electric furnace application was the tapping of the first heats from the two 40 ton three-phase Heroult furnaces of the Government armor plant at Charleston, West Virginia. Molten steel from the basic open hearth furnaces is delivered to these furnaces where the refining is completed, resulting in the production of a very high class steel. At the Pittsfield plant of the General Electric Company there was completed recently a run on an induction furnace when the 555th heat was poured. The service is particularly hard, as high silicon steel is melted on a basic lining with excellent results.

There has probably been more development in the control field during the past year than in any other single line of apparatus. All of this work tends toward the simplification of magnetic control, the standardization of parts, the reliability of operation, and the life of wearing parts, contacts, and arc chutes.

An item under keen investigation in the steel plant, which as yet has hardly reached the development stage, is the electrification of the plant railroad yards, with a view toward eliminating steam locomotives for transportation. This probably presents a larger field for development effort than any other single item in the plant, as it is felt that railroad electrification has not kept pace with mill electrification.

The greatly reduced operations in the steel industry of to-day make it necessary to cut all costs of pro-

duction to a minimum, and this field of development has thus the greatest stimulus and should go attached with unprecedented effort.

Dependable Driving Equipment

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IN THE electrification of the main rolls of a large steel mill, the reliability, cost of maintenance and life of the electrical equipment are important items for consideration. These items are all discussed in an article in this issue of the JOURNAL by Mr. W. S. Hall, in his description of the first reversing mill equipment installed in this country. He also outlines the advantages obtained by electrification which were not capitalized when the decision was made to drive this mill by electric rather than by steam power.

This equipment, which represented an entirely new venture, has operated fourteen years with delays which, during the last few years, are almost negligible—in fact during the thirteenth year no delays whatever were charged against the equipment. If a reversing engine had been installed on this mill, it would now be considered out-of-date, both from the point of view of economy and maintenance, but today this motor drive is just as economical as the day it was installed and, instead of an increasing number of breakdowns, an interruption from the driving equipment is almost a thing of the past.

Although this first equipment has operated during the entire period with delays amounting to but one-half of one percent, this is not necessarily an exceptionally good record. By referring to the Proceedings of the Association of Iron & Steel Electrical Engineers, it will be noted that the first reversing blooming mill motor equipment driving the 34 inch mill at the Steel Company of Canada operated four and one half years during the war period with delays amounting to 0.04 percent.

Recently the chief engineer of one of the large mill manufacturers made the statement that he would recommend electric drive in preference to engine drive, even assuming that the cost of operation with the electric motor was slightly in excess of that with the engine. He has studied the situation sufficiently to evaluate those advantages of the electric drive which are more or less intangible.

The introduction of electric drive on our rolling mills is going to establish a new idea of service which rolling mill engineers and superintendents will expect from their equipment. If motor drive can operate with practically no delay, interruptions caused by the mill machinery will be more noticeable, and we can expect that higher grade mill machinery will be installed in the future.

The fact that the equipment described by Mr. Hall has remained almost intact, particularly the bearings, very clearly indicates that the inherent characteristics of electric drive make it better adapted to rolling mill service than the engines which it is superseding

The most remarkable statement in Mr. Hall's article is that "after fifteen years of service no definite conclusion can be formed as to the life of a winding on this class of equipment."

Mechanical Maintenance of Mill Equipment

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RELIABILITY is the mill operator's yardstick for measuring his equipment. Frequent failure of a part on which is dependent the steady flow of steel through the mill dooms the offender to the scrap heap as soon as a more reliable replacement is feasible.

Steel is produced by men and machines, and the reliability of the machines is a direct function of the ability and reliability of the men. The best mill operators give their equipment a chance by proper installation and the exercise of eternal vigilance in heading off deterioration. Good equipment badly installed loses much of its inherent reliability.

The production of steel imposes such drastic rough and tumble service on equipment, that it has seemed almost impossible to make mill apparatus that will run over long periods of time without failure. The continuation of failures after prolonged endeavor to secure their complete elimination has caused the growth of a conviction that all mill equipment is heir to trouble and, in some instances, a careless habit has grown up, resulting in more or less condoning failures.

The introduction of electrical equipment has eliminated some of the ills heretofore fundamentally associated with other forms of drive. Electric drive, however, retains certain mechanical features which will give trouble, unless proper precautions are taken. There is a nebulous region between horse sense precaution and finicky refinement. Messrs. Pruger and Deesz, in this issue of the JOURNAL, deal constructively with the practical side of trouble elimination by the removal of contributary causes. The article brings out strongly that a flexible coupling, instead of a cure-all for careless workmanship, is a device which assists in caring for errors and vibrations which are fundamentally unavoidable. It emphasizes the necessity of keeping all parts in proper balance, and shows that tribulation treads hard on the heels of neglect. While bringing out that most of the ills of mill equipment may be traced back to the fundamentals of alignment and balance, the central thought may be stated in a phrase—"and the greatest of these is alignment."

Mill operators will find that study and practice along the lines suggested in this article will help establish the boundaries between fundamental requirements and useless frills, and will show where concentrated attention on their part will minimize failures.

Variable Speed Induction Motor Sets

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INDUCTION motors are primarily constant speed motors and have been applied principally on loads which require rather flat speed regulation and only one speed. Occasions arise, however, especially in connection with large steel mill motors, where adjustable speed is desired, and this can be secured by the use of auxiliary commutator machines which allow the main motor to operate at other than its normal synchronous speed, as determined by the frequency of supply and the numbers of poles.

In a direct-current motor, the speed can be varied by changing the field strength by means of a field rheostat. When the speed changes, the frequency in the rotor core and coils also changes in direct proportion to the speed, the same as in any alternator, but this alternating current is converted into direct current by the commutator and brushes so that a change in speed means only a change in voltage.

In an induction motor there is no field circuit to vary, since the field is supplied by the same winding which carries the main working current, so that this method is not available for speed changing. The line frequency is usually supplied to the stator and produces a rotating field whose speed in the air-gap is proportional to the frequency and inversely to the number of poles, i.e., r.p.m. $= \dfrac{f \times 120}{p}$. This rotating magnetic field will generate, in a rotor which is wound for the same number of poles as the stator, a variable voltage and frequency, depending on whether the rotor is stationary or rotating.

If the rotor is stationary, the flux cuts the rotor conductors at primary frequency and, as the voltage generated is proportional to the speed of cutting the rotor conductors, the secondary voltage will be proportional to the ratio of turns on stator and rotor, Fig. 1. If the rotor is running in the same direction as the stator field but only one-half as fast, the primary flux is cutting the rotor conductors at one-half the speed it was before and will generate only one-half the frequency and one-half the voltage. At synchronous speed the rotor is turning at the same speed as the field. The primary flux does not cut the rotor conductors and so generates no frequency or voltage.

At speeds above synchronism, the rotor again cuts the primary field and induces a frequency and a voltage which increase in direct proportion to the speed above synchronism, but in this case, the rotor conductors are going faster than the field, while before, the field was faster than the conductors, so that the direction of the induced voltage is reversed.

The torque in an induction motor is produced by the reaction of the primary field on the ampere-turns of the rotor. Since the primary field is constant, being supplied by a constant voltage, each value of current then corresponds to a definite value of torque. This value of current will not change when only the speed is changed, but the voltage on the rotor will change as shown above.

With varying speed at constant torque the output, which is equal to $\dfrac{torque \times r.p.m.}{5250}$, will be proportional to the speed, i.e., at one-half speed, one-half full load in horse-power; at full speed, full load; at one and one-half speed, one and one-half load. Since a constant torque requires a constant current input at constant voltage, the power input to the primary corresponding to full-load torque is constant at the full load value, regardless of speed, while the output in mechanical power is proportional to the speed, so that the difference must appear as electrical power at the collector rings.

At standstill, the output in mechanical power is zero, so that the entire input must appear as losses in the machine and electrical output from the rotor. In this case the motor is only a transformer. As the rotor speeds up, the motor does work in proportion to the product of torque and speed and only the remainder, which is proportional to the difference between the full speed and the given speed (known as slip), appears at the collector rings as electrical energy. At full speed, all the primary input (except losses) is given out as mechanical output and no electrical output is available at the collector rings. In the above, the mechanical output has been the difference between the primary input and the power available at the collector rings. We have gradually increased the mechanical output by decreasing the power taken from the collector rings to zero and, evidently, to obtain any more power, we must make this quantity less than zero, or in other words, take negative power from, or give positive power to, the rotor. If this is done the mechanical power becomes the sum of the primary input and the rotor input, increasing as the power to the rotor is increased. Since the rotor current is fixed for a given torque, the variation in power must be made by changes in the value and direction of the secondary voltage.

Therefore, the only way to cause an induction motor to run at speeds other than near its normal synchronous speed, is to supply or consume a variable voltage at the collector rings, keeping in mind also that the frequency of this voltage must always be the same as supplied by the rotor of the main motor.

The problem then resolves itself into finding a means of using up the energy which appears at the collector rings below synchronism and supplying power to the rings for operation above, all this being done automatically with changing loads and speeds. There are various ways of doing this, all of which are practical and can be used for steel mill service.

The Kramer System is a method in which the variable voltage, variable frequency power from the collector rings is converted into direct current by using a rotary converter in the rotor circuit of the main motor. The direct current so produced is used up by a

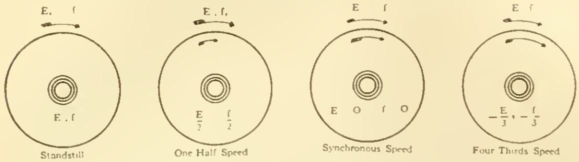

FIG. 1—SECONDARY VOLTAGE AND FREQUENCY AT DIFFERENT SPEEDS

direct current machine which can be mounted on the main motor shaft and add its torque to the main motor torque, thus producing a constant horse-power set, Fig. 3, or the direct current power can be used to drive a motor-generator set and return the power to the line, producing a constant torque set. The speed is varied by changing the excitation on the auxiliary machine, which produces a change in its counter e.m.f.

This system has its principal field in ranges below the synchronous speed of the main motor, since the rotary converter fails to function properly when the main motor approaches its normal speed and the voltage and frequency fall below approximately four to five percent of the open circuit values.

FIG. 2—INSTALLATION OF KRAMER EQUIPMENT

This set is fairly cheap, as the main motor is made with a normal speed which is the highest speed required by the mill and a standard rotary converter can usually be used and very little changes are necessary for the auxiliary direct current motor, so that very little development is required. Besides this, all the apparatus is familiar to operating men and everybody knows where to look for trouble if any occurs. The only objection is that, in case the auxiliary apparatus is out of commission, the mill when operating with the motor alone, will be at the high speed where some sections could not be rolled which might possibly be rolled if the motor were of medium speed.

These sets can be operated above synchronism if means are provided for bringing them above, and in some cases, where the friction load is light, there is a possibility of getting above without auxiliary means, merely by reversing the field on the auxiliary machine. When operating above, the lower limit is approximately four to five percent above synchronism, the same as for below.

The Scherbius System is so devised that it takes energy direct from the collector rings of the main

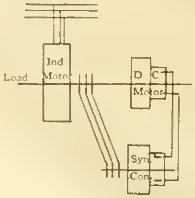

FIG. 3—SCHEMATIC DIAGRAM OF KRAMER SYSTEM

motor and converts the electrical power into mechanical power in one auxiliary motor. This motor is a polyphase compensated commutator motor and usually drives a generator which can be synchronous or induction but is generally induction. This scheme gives a constant torque set, as the excess power is returned to the line.

The commutator motor can also be mounted on the shaft of the main motor in which case it makes a constant horse-power set. However, this scheme is not practical as the speed of the main motor is usually very slow. Hence a large slow-speed commutator motor would be required, which would be special for practically every speed and rating, while when driving the induction generator the speed can be made high and can be standardized for a rating independent of motor speed.

The Frequency Converter System is a scheme in which the low frequency of the rotor circuit is converted to another higher frequency, which is used in auxiliary alternating-current apparatus for constant horse-power sets or returned directly to the line through transformers in constant torque sets. This system is explained more in detail than the others as it is new to most people and includes some relations which occur in all adjustable-speed induction-motor sets.

In the constant torque outfit, the frequency converter is mounted on the same shaft as the main motor and usually has the same number of poles. This frequency changer is similar to a rotary converter, having an armature with collector rings on one end and a commutator on the other. The stator does not have any winding but consists merely of a magnetic keeper to decrease the magnetizing current. The brushes on the commutator are spaced so as to collect polyphase currents, i.e., three brush arms per pole pair for three phase and six per pole pair for six phase. The col-

lector rings are connected to a source of variable voltage obtained from the same line which supplies the primary of the main motor.

If this set is rotating at synchronous speed, the frequency changer acts like a direct current rotary converter and direct current is generated on the commutator side when line frequency is on the collector rings. In order to explain this action, the converter can be considered as two separate machines, an in-

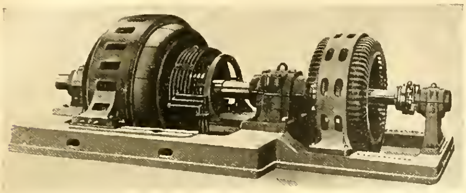

FIG. 4—MAIN MOTOR OF FREQUENCY CONVERTER SYSTEM
At the Scullen Steel Company, St. Louis, Mo.

duction motor and a direct current generator. The line frequency is supplied to the rotor so that the field rotates around the rotor periphery at synchronous speed and, since the rotor itself is rotating in the opposite direction at the same speed, the field itself is standing still in space. These stationary fields correspond to the field poles of the direct current machine so that the voltage at the brushes on the commutator is direct current. The voltage which appears on the commutator bears a definite relation to the voltage on the collector rings, the same as on a standard rotary converter, i. e., the voltage will be proportional to the voltage supplied to the collector rings and will not be changed by rotating the armature at different speeds.

At two-thirds speed, the field in the frequency changer will not be stationary, but will rotate backwards at one-third speed since the field is rotating backwards at normal speed with respect to the rotor and the rotor is rotating forward at only two-thirds the normal speed. Since the brushes are stationary, the frequency which appears at them will depend on the speed of the field in space, in this case one-third of line frequency.

At four-thirds speed, the rotor is rotating forward faster than the field on the rotor periphery is rotating backwards, so that the speed of the field in space is one-third of normal speed forward. If the frequency below synchronism is considered positive and that above negative, it is seen from the above reasoning that the frequency of rotation plus the frequency on the commutator in Fig. 6 is equal to the frequency on the collector rings. This applies whether the frequency on the collector or the frequency of rotation is kept constant. By frequency of rotation is meant that frequency which corresponds to the speed and number of poles. In these sets, the frequencies in the different machines must always be correct or the machines will hunt and pull out of step, drawing large currents from the line.

The relation of frequencies can be shown to be correct for the constant torque set as follows. The frequency at b is the slip frequency sf, the speed being $(1-s)f$. As shown before, the frequency on c plus the frequency c equals the frequency d, or in other words, $sf + (1-s)f =$ the frequency on d which is f so that the frequency of d, considered through the main motor, is equal to that of the line and can be connected to it.

In order to change the speed in this set, means are provided between d and the line to vary the impressed voltage applied to the collector rings. When the voltage on the collector rings d is changed, the speed adjusts itself until the current is just sufficient to carry the load. As an example, assume that the speed is to be increased when the main motor is running below synchronism at constant torque. The load current in the rotor is produced by the difference between the voltage produced by the rotor of the main motor and a smaller voltage from the commutator of the frequency changer. Now to increase the speed below synchronism, the voltage on the commutator is decreased. This allows the larger difference between the main motor voltage and the commutator voltage to send more current through the rotor, thus increasing its torque and accelerating the rotor. As the rotor accelerates, the voltage from the rotor decreases until the difference between the two voltages is the same as before and the normal current is flowing in the rotor circuit.

A numerical example of the action may be clearer. Assuming a set operating at a normal speed of three percent below synchronism and requiring a secondary

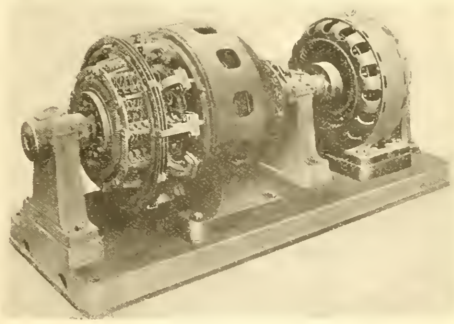

FIG. 5—FREQUENCY CONVERTER
At the Scullen Steel Co., St. Louis, Mo.

voltage of 30 volts to send the necessary current through the rotor circuit.

Next, a voltage of 70 volts is applied to the collector rings, which opposes the 30 volts generated in the rotor of the induction motor, and causes a decrease in the rotor current and torque so that the rotor slows down. In slowing down, the rotor voltage increases and, in order to produce enough current in the rotor

circuit to carry the load, the generated rotor volts must exceed the counter voltage from the frequency changer by 30 volts or it must be equal to 100 volts. The generated secondary voltage is proportional to the slip and since 30 volts corresponded to three percent slip, 100 volts gives ten percent slip.

If the voltage of 70 volts is reversed so as to help the 30 volts generated in the rotor of the induction motor, the current which would flow in the rotor circuit would be much larger than that required to carry the load and the motor speed would increase. As the motor approaches synchronous speed the generated voltage will decrease to zero and above synchronous speed the voltage will increase again but in the opposite sense, so that it would subtract from the 70 volts supplied by the frequency changer, increasing as the speed increased, until only 30 volts were left to produce the necessary current for the load. This would be when the generated volts were 40 volts or when the motor was running at four percent above synchronism. From this it is seen that with the same voltage values on the frequency changer, the speed change is an equal amount above and below the normal speed of the induction motor and not above and below the synchronous speed.

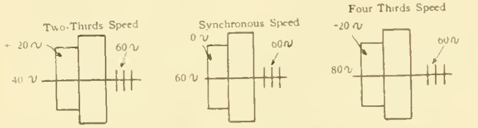

FIG. 6—FREQUENCY AT COMMUTATOR OF FREQUENCY CHANGER AT VARIOUS SPEEDS

The usual set is slow speed and the frequency converter becomes extremely large when made with the same number of poles as the main motor, so that this system works out best as a constant horse-power set, in which a synchronous motor is mounted on the main motor shaft and the frequency converter is driven at some higher speed by a synchronous motor, as shown in Fig. 8. The auxiliary synchronous motor has the same number of poles as the main motor and the driving motor for the frequency converter has the same number of poles as the frequency converter. In this case the frequency generated in the auxiliary machine is proportional to the speed, or is one minus the slip $(1-s)$, being less than the line frequency below synchronism and greater when operating above.

The relationship of the frequencies in this set can be shown as follows. In this case the phase rotation between the rotor of the main motor and the commutator is reversed with respect to the other set, so that the slip frequency has a negative sign.

The line frequency f is supplied to the stator a so that the slip frequency at b is sf and the speed is $(1-s)f$ as before. In this case, the frequency changer is driven by a synchronous motor or the speed of rotation is f. As before, the commutating frequency plus the rotational frequency equals the collector frequency and, keeping in mind the reversal of lead between b and c, $c + f = d$ or $-(sf) + f = (1-s)f$ which agrees with the frequency generated by the auxiliary alternating current generator g which has the same number of poles as the main motor and runs at the same speed, i. e., $(1-s)f$.

The speed in this set is changed by changing the excitation on the auxiliary generator g. For the lowest speed, the field is at its maximum in one direction, and to increase the speed the field is weakened until

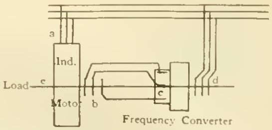

FIG. 7—SCHEMATIC DIAGRAM OF CONSTANT TORQUE FREQUENCY CONVERTER SYSTEM

at no field the set is operating slightly below synchronous speed. To increase the speed, the field is reversed and again increased to the maximum value. Since the field copper is usually the limit on synchronous machines, the same field above and below synchronism will generate a larger voltage above synchronism due to the increased speed, than is generated below and this difference more than offsets the decrease in range above synchronism due to the normal slip when no field is on, and gives a larger range above than below.

These sets also allow of easy phase correction by changing the position of the brushes on the frequency converter. If the voltage from the commutator of the frequency changer is in direct opposition in time to the rotor voltage, there will be no change in power factor conditions, but if the brushes are shifted one way or the other, the voltage impressed on the rotor is not in line with the rotor voltage and can be considered as two voltages at right angles to each other, one in line with the rotor voltage and the other at right angles

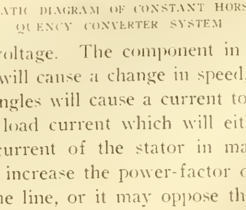

FIG. 8—SCHEMATIC DIAGRAM OF CONSTANT HORSE-POWER FREQUENCY CONVERTER SYSTEM

to the rotor voltage. The component in line with the rotor voltage will cause a change in speed, but the voltage at right angles will cause a current to flow at right angles to the load current which will either assist the magnetizing current of the stator in magnetizing the motor and so increase the power-factor of the current taken from the line, or it may oppose the main motor magnetizing current and cause the main motor to draw more magnetizing current from the line and so decrease the power-factor of the main motor. Moving

the brushes one way will raise the power-factor while a movement in the opposite direction will decrease the power-factor.

The magnetizing current taken by the motor is constant, so that a constant voltage at right angles to the working current will be required to give the same power-factor at a certain torque. Since the voltage on the rotor near synchronism is small compared to that when near the limits of the speed range, a larger shift will be necessary near synchronism to give the same voltage than is necessary near the limits of the speed range. Therefore, means are provided for changing the brush position for different speeds to obtain approximately constant power-factor.

This can be done either by actually shifting brushes or by shifting the center line of the poles on the driving motor which is the easiest practical way. The driving motor is wound with a distributed field and the center line of the field is shifted by varying the excitation on the different parts of the windings by means of a field rheostat which is governed by a relay in the primary circuit.

Substations for Reversing Mill Motors

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DUE to the importance of keeping steel mills in continuous operation, careful consideration should be given to every detail in their design. The amount and nature of the electrical equipment required for the operation of a mill is extensive and varied*. In many cases, it is difficult to house this machinery properly and locate it efficiently. It is located out in the mill, subject to dirt and dust from which it must be protected. This location is determined by the position of the rolls. In deciding the layout of the mill, the substation location is usually given secondary consideration. In many cases, the equipment is to replace a steam engine drive and must be located approximately in the space occupied by the engine. Thus, to a great extent, the physical design of the building is limited.

Properly speaking, the designing of the substation means assembling the equipment and building in the proper location around the reversing mill motor. It is obvious that to get the desired results under the above conditions, careful consideration must be given to those important features that go to make a well designed substation. These features are space, accessibility, visibility, symmetry and economy.

SPACE

A "cramped" substation is poorly designed, yet this is one of the most common faults. Engineers often seem to forget that machinery may need to be repaired and lose sight of the importance of space for depositing parts of the machinery when it is necessary to make these repairs. Too much importance cannot be placed on this feature. Loss of production in a steel mill is of far greater importance than economy of space. If a mill is shut down for repairs, such repairs must be made quickly, and ample space must be available for the disposition of removed parts and parts required to make the repairs. The station, therefore, should, have adequate room to deposit the upper half of the motor frame and any other removed parts while the armature is being changed.

ACCESSIBILITY

The equipment should be readily accessible with the crane hook or other means for its removal. Time lost in this operation further impairs production. It should also be easily accessible to the station attendant. Especially is this true of the tie panel, slip regulator, switching and control equipment. The bed plates for the motor and flywheel motor-generator set should be set in the floor to a depth permitting only about 1.5 in. projection above the floor line. This will greatly increase the accessibility of the bearings for inspection. Quite frequently the floor line of the mill is at a lower elevation than can readily be obtained in the motor room. To bring the motor to the mill elevation requires that it be set in a pit. This pit should be of sufficient dimensions to permit access to the motor on all sides. If the pit and motor foundation are made at the same time and completed before the motor bed plate is put in place, a space of at least one foot must be provided all around between the motor foundation and the pit floor for lowering and adjusting the bed plate onto the foundation as shown in Fig. 1. This space will be sufficient for the removal of the crane hook and any necessary adjustment of the motor bed plate. After the plate has been properly placed and rigidly bolted, the space can be filled in to the level of the pit floor. The best arrangement, of course, is not to put in the pit floor until the bed plate is on the foundation.

VISIBILITY

All of the equipment, especially the slip regulator and switching equipment, should be visible to the station attendant. It is very important that he be able to see from his position at the switchboard the movement and position of the regulator arm at the time of the starting of the flywheel set. Therefore, the slip regulator should be set out in the room so as not to be obscured by any other piece of machinery.

*See an article on "Motor Driven Plate Mills" by F. D. Egan, in this issue.

SYMMETRY

A well-balanced and symmetrical substation is much to be desired. No one likes a station that has no symmetry regarding location of apparatus, but looks as if the equipment had been installed where it happened to be placed when received. The essential features should not, however, be sacrificed for symmetry. Usually, if consideration is given this feature of design before the building dimensions are definitely

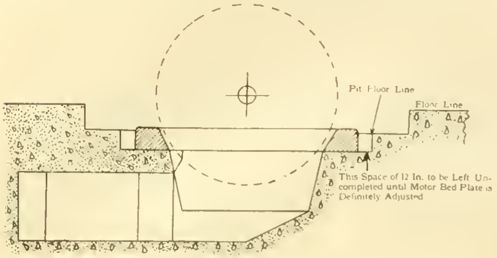

FIG. 1—MOTOR FOUNDATIONS

Showing method of leaving space for bed plate adjustment. This space to be filled in after the bed plate is set on the foundation.

settled, fairly good results can be obtained. But in stations where this feature has not been considered in determining the substation dimensions, one is indeed fortunate if he can combine the essential features and yet obtain the desired features of symmetry. Fig. 2 shows the floor plan of a reversing mill motor substation that combines the above features to a very reasonable degree, with the exception of the air washer. The location shown for it was necessary on account of other machinery being located beyond the blower motor, thus preventing the reversing of the washer equipment. Space is available between the direct-current control board and air washer for depositing the removed parts when necessary to make repairs on the reversing mill motor. The available space is however, more or less cramped, making it awkward to dodge the control board. It is obvious that the design of the station would have been much improved, if the air washer could have been reversed.

ECONOMY

Running connecting rods for hand operated circuit breakers in trenches is unsatisfactory. The trench is a catch all for dirt and interferes with keeping the floor clean. It adds to the expense of laying the floor and requires the purchasing of iron covering for the trenches. Economy may not be considered an important feature in the design of such a station, but precautions should be taken to eliminate unnecessary waste, especially where no real value is obtained by the additional expense. Most stations are free of this fault. More often it is the case of carrying economy too far and eliminating some feature that would add to the reliability and efficiency of the station. The important feature that seems to fall most often under the economic necessity for elimination is the basement. In most stations, the elimination of a basement is poor economy and a detriment to properly designing the station. Some of the apparatus required for a reversing mill could more conveniently be located in the basement than any other place in the station. Especially is this true of the blower and air washer. This equipment can be installed in the basement at a lower cost and will operate more efficiently than on the main floor. Figs. 3 and 4 show a photograph and section of a double unit reversing mill motor substation with a basement and the air washer and blower installed therein.

SECONDARY DESIGN FEATURES

There are certain secondary features that assist materially in making a well designed station. These may be designated as the location of the equipment with respect to the apparatus to which it is closely associated, and the method of installing the connections between the equipment.

AIR WASHER

The location and installation of the air washer and blower is a special problem in itself. The size of

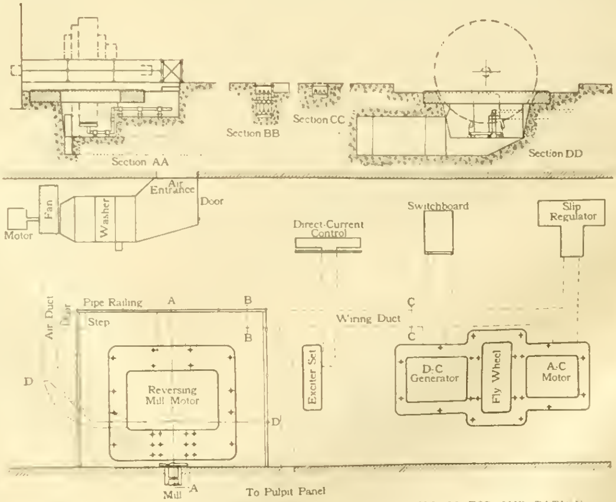

FIG. 2—FLOOR PLAN FOR SINGLE UNIT REVERSING MILL MOTOR SUBSTATION

the equipment is determined by the volume of air required by the motor to keep the windings at the proper temperature. Its location must be at some point where outside air can be taken into the washer. This point must be relatively close to the motor, as a long air duct decreases the velocity of the air and, therefore, the volume entering the motor. The duct should also be

as straight as possible. Bends and turns reduce the velocity of the air rapidly, especially if they are short turns. For this reason, when it is impossible to eliminate bends in the air duct, these turns should be made with long radii to reduce the friction loss to a minimum.

DESIGN AND CONSTRUCTION OF AIR DUCT

The air duct may be made either of sheet steel or concrete. If of concrete, care must be exercised in finishing the walls. The velocity of the air is so great that it cuts the walls and carries particles of concrete and sand into the motor winding unless the walls are smooth. In addition, the walls should be painted once or twice a year with a hard finish asphalt paint. An entrance, should be provided for workmen to enter the duct to do painting or any necessary repairs. In a station without a basement it is much simpler and more permanent to make the duct of concrete than to arrange for the protection from rust of a metal duct buried in the earth underneath the station floor. With a metal duct the best construction would still be a concrete duct, steel lined.

Outside Entrance to Duct—Precaution must be taken to protect the outside air entrance to the air washer from snow and icy air. The entrance should be provided with a door that closes the outside entrance and opens an entrance from the motor room, as shown in Fig. 4. Two separate doors should never be provided for these entrances unless they interlock so that the attendant cannot close one without opening the other. In continuously warm climates the double door feature is unnecessary, the outside entrance being sufficient.

FLY-WHEEL SET

The location of the fly-wheel motor-generator set should be selected with a view of giving the station a balanced appearance and of reducing the length of the tie circuit connection between the generator and the motor. As the location of the mill motor depends entirely upon the position of the mill, the flywheel set, which has somewhat the same physical dimension as the motor, should be located to off-set the motor, giving a symmetrical and balanced appearance to the station. The location, of course, is flexible, depending upon the physical design of the station, but, in general, it should be as near as possible to the motor, as the tie circuit between the generator and the motor is usually expensive to install and considerable amount of copper is required to carry the heavy current. This flexibility in locating the flywheel motor-generator set is shown clearly by Figs. 2 and 3.

TIE CIRCUIT BREAKER PANEL AND EXCITER SET

In locating the flywheel set and the tie connection between the generator and the motor, the tie circuit breaker panel and the exciter set must be considered. Both of these are connected in the tie circuit. Therefore, provision should be made for properly locating each of these somewhere along this connection. Usually they are located near each other. There is no essential reason for this location except that having these two located together usually adds to the balanced appearance of the station. The connections from the tie circuit into these two pieces of apparatus are made with copper strap. These connections are uninsulated and, if left exposed, afford more or less danger from accidental contact. The appearance and safety feature will be considerably improved by enclosing the rear of the tie panel in grill work*, having a door for accessibility in the rear, and enclosing the connections to the exciter in wood moulding. Fig. 5 shows an exciter connection enclosed in wood moulding. It consists of a board one-half to one inch thick having three wooden strips, nailed on it, one on each outside edge and one in the middle, forming two grooves, with the width of each groove the same as the copper strap making the connection. The two strips on the outside edges should be at least one-half inch wide. The thickness should be equal to or slightly more than the thickness of the copper connections. The width of the middle strap should be the same as the distance between the two connections.

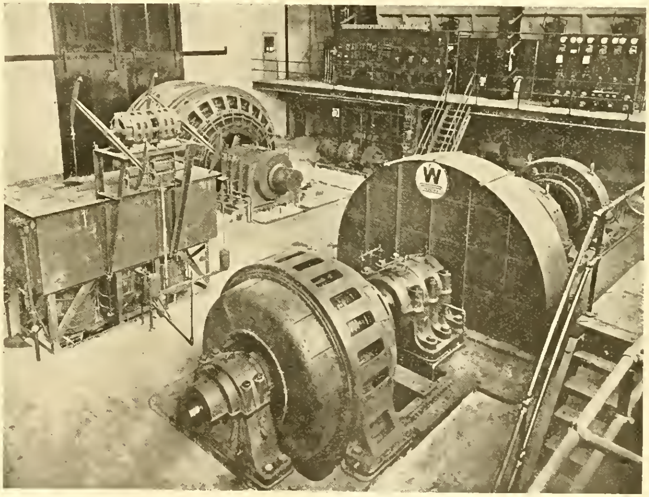

FIG. 3—STATION LAYOUT OF DOUBLE UNIT REVERSING MILL MOTOR WITH BASEMENT AND BALCONY FOR SWITCHBOARD

*As shown in Fig. 12 of Mr. Egan's article in this issue, p. 321.

The cover should consist of a board having the same dimensions as the base. Small wood screws can be used to hold it in place. Any color or finish can be applied to the moulding. A glossy black paint to resemble the finish of the exciter set makes a very satisfactory installation.

SLIP REGULATOR

The slip regulator, should be located so as to be visible to the station operator from his position at the

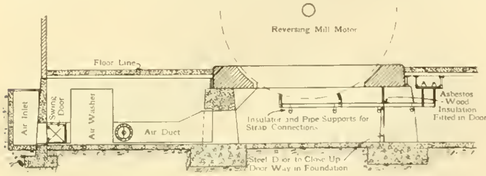

FIG. 4—SECTION OF A REVERSING MILL SUBSTATION
Showing location and construction of air washer, blower and air duct, foundation of mill motor and method of making connections.

switchboard. The distance between the regulator and the motor and the distance to the station drainage system should be taken into consideration. The connecting leads between the regulator and the secondary of the motor are comparatively heavy, and therefore, to eliminate unnecessary expense, the distance between the regulator and the motor should be reduced to a minimum. The regulator in all cases should be provided with a pit of sufficient dimensions to hold the entire capacity of electrolyte. This pit should be provided with an outlet connecting to the drainage system. This feature will in many cases influence the selection for properly locating the regulator.

PRIMARY PANELS AND SWITCHING EQUIPMENT

The proper location of this equipment is determined to a very great extent by the point of entrance of the incoming line. The switching equipment should be located as near this point as practical, thereby eliminating any long run of incoming leads. If the oil switches are manually operated, the switchboard panel, having mounted thereon the oil circuit breaker handles and cover plates, should be placed in front and near the structure supporting the switching equipment. This location will eliminate any long run of connecting rods and instrument cables, and will reduce the cost of providing trenches for the circuit breaker connecting rods. If the circuit breakers are electrically operated, the above conditions affecting the location of the panels need not be considered, except to the extent of reducing to a minimum the length of instrument and control cables and their respective conduits. The electrically-operated equipment thus permits greater flexibility of arranging and locating the panels. As pointed out, these panels should be located so that the whole station equipment is more or less directly under the operator's vision from any point at the switchboard. This condition can be obtained more readily and usually with less cost and trouble with an electrically-operated switching equipment, than with a manually-operated installation. Fig. 6 shows a section of a pipe frame structure supporting manually-operated switches and equipment located directly in the rear of the panels. Fig. 7 shows a section of an electrically-operated circuit breaker cell structure also located directly in the rear of the panels.

In stations requiring extensive switching equipment, such as additional equipment for incoming lines, feeders for rotary converters, motor-generator sets, and lightning protective equipment for the incoming lines, the above arrangement will usually be found difficult to carry out. A crowded condition usually results in any attempt to locate the equipment all on the same floor. If the substation has a basement and the equipment is as extensive as indicated above, the oil switches can be located to very good advantage in this basement and the switchboard panel immediately above on the main floor. The lightning arrester equipment should be mounted near the incoming line. If inside the building, its location may be either on the main floor in the rear of the board, or on a small balcony above. If outside the building, it may be placed advantageously on the roof of the substation, especially if outdoor space is at a premium. Various other arrangements of the equipment may be carried out depending upon the conditions in each individual case.

FIELD CONTROL EQUIPMENT

The location of the field control equipment is not influenced by its electrical relation to any other equipment, except in a small degree to the mill operator's

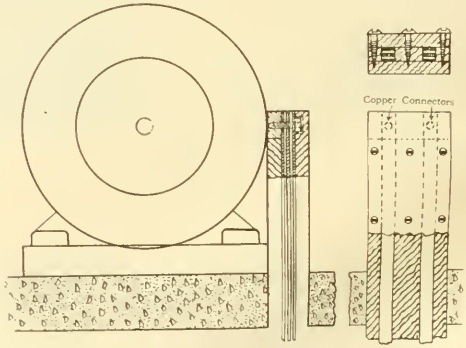

FIG. 5—EXCITER CONNECTIONS
Showing method of enclosing leads in wood molding.

pulpit. This relation, however, is only relative and is due to the number of wires between it and the master control switch and pulpit panels. It is interconnected with most of the equipment in the station. The wires, however, are small and relatively few, except in the case of the master control switch and pulpit panel. In order to reduce the length of these leads and their conduits it may be advisable to locate it in the station near the operator's pulpit. The mill motor is always located

at this side of the building and as its fields are connected to the control panel by a number of wires, this location will in most cases be found to be the most satisfactory. This location should not, however, be adhered to, to the detriment of other important features of design, such as symmetry and space. The amount saved in cable and conduit will usually not be sufficient to warrant this sacrifice.

This control board is usually of the same height and general appearance as the primary panels. Therefore, if it can be erected near and in line with the primary panel, it will add in most cases to the general appearance of the station. This station shown in Fig. 2 has such a location of the control board .

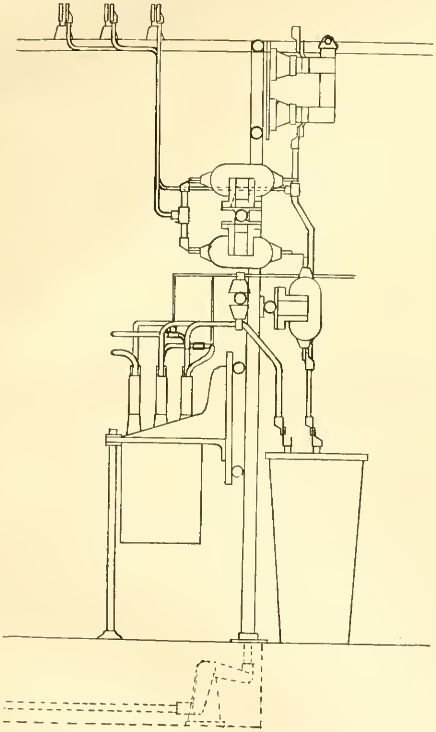

FIG. 6—SECTION OF SWITCHBOARD
With a pipe structure supporting the circuit breaker equipment mounted in the rear.

GRID RESISTORS FOR MOTOR AND GENERATOR FIELDS

The grid resistances are connected to the various contactors of the control board. The operation of these switches cuts in and out the various grids as desired. Therefore, to reduce troubles and cost of installing, these resistance grids should be mounted as near this board as possible. If mounted on the floor back of the board, considerable space and extra wiring is required. To mount them in the basement underneath the board some attention to ventilation may be required. The most satisfactory location is to arrange them at the top and in the rear of the panels, as shown in Fig. 8.

SWITCHING EQUIPMENT

The correct installation of the switching equipment is of such importance to its successful operation that careful consideration should be given to its erection. The most important feature in the erection of this equipment is the mounting. If the circuit breakers are mounted on a masonry wall, the supporting bolts should be either well embedded or, if the walls are thin, run through the wall and a plate added under the bolthead. If supported on pipe framework, they should be placed so that no excessive strain is exerted upon any section of the pipe. The pipe structure should be well braced, rigid and able to withstand the strain of opening and closing the circuit breakers with-

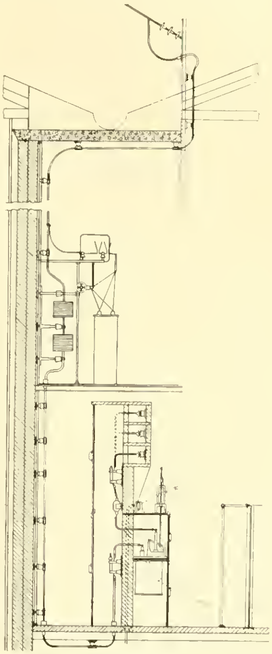

FIG. 7—SECTION OF SWITCHBOARD IN STATION WITHOUT BASEMENT
Showing electrically-operated circuit breaker cell structure mounted in the rear of the panel board. In a station having a basement it would be desirable to mount this circuit breaker structure in the basement and mount the switchboard on the main floor above and in front of the lightning arrester equipment. Another alternative to either of the above schemes, which is frequently desirable, is to mount the lightning arrester equipment on the substation roof or in a gallery above the floor.

out excessive vibration. The large circuit breakers should be supported both in front and rear, and these supports should be adjusted to share the load evenly.

The operating mechanism should be checked and adjusted. Especially is this important with the hand-operated circuit breakers. The remote control mechanisms should be so arranged, if possible, that the connecting rods are in tension when closing. The mounting bolts of the bell crank bearings should be

well embedded in their foundation. A large washer or plate should be put under the head to give extra strength to their setting in the concrete. If the force to close the circuit breaker is such as to tend to pull the bell crank bearing loose, adjustment should be made by means of the set screw on the circuit breaker frame and the correct proportioning of the connecting rods. If the screw is out too far, it will prevent the circuit breaker from closing. In attempting to force the circuit breaker closed, the operator may thus pull up the bell crank bearings or break the closing handle. It is important also that this set screw be not in too far; otherwise the travel will be too great and will injure the contacts.

Before the circuit breaker is put into service, it is important to see that the brushes make good contact, thus preventing trouble from heating and arcing. Adjustment of the brushes is sometimes necessary, especially in repair work. These adjustments can easily be made by moving the contacts slowly in and out and noting if the moving contacts press well against the stationary contacts.

The structure for supporting the cirucit breakers, whether masonry or pipe, should be erected complete before any apparatus is mounted thereon. In erecting the cell structure, provision must be made for all necessary openings. The conduit for instrument and control wiring must all be put in and the mounting bolts for bus-bar supports, disconnecting switches, transformers, etc., be in place before the concrete or brick work is completed, as considerable trouble and expense will be involved if an attempt is made to do such work after the completion of the masonry structure.

METHOD OF INSTALLING CONNECTIONS

The method and type of construction used in making the connections between the various machines depends upon the design of the building. If the station is provided with a basement, the connections are run underneath the floor, either in conduit or open and supported from the basement ceiling. Fig. 3 shows a substation with a basement, in which all main leads are run open, supported from the basement floor. The small wiring and control cable is run in conduit, which is supported from the basement ceiling. If the connections are run in the open, the leads should either be bare copper rod or strap, or flame proof insulated cable, except the connections between the generator and mill motor. These should always be copper strap, as the current is too large on this circuit for the economic use of cable.

In stations not having a basement, either of two general schemes may be used. The first provides for running all leads, except the tie circuit between generator and mill motor, in conduit placed in the floor. The tie circuit leads are run in a trench cut in the floor. This trench is usually about two feet wide by two feet deep. The copper strap leads are supported on insulators mounted on cross pieces of iron pipe or channel and are placed about three inches from the bottom of the trench and extend three or four inches into the walls of the trench on each side. The construction of this trench is shown in section *CC*, Fig. 2. The cover for the trench is a steel floor plate. The trench is framed with an offset to permit the cover to come flush with the station floor. The conduit for the remainder of the leads may be either iron or fibre, depending upon the size of leads. If the leads are too large for use in one conduit, the alternating-current leads may be run separate in individual fibre ducts.

In the second scheme, trenches are cut in the floor. All main leads are of bare copper strap supported on insulators mounted on channel iron or pipe similar to that used for the tie circuit described above. These supports for the insulators are mounted approximately three inches from the bottom of the trench. The conduit for the small wiring and control leads is laid in the bottom of the trench. This scheme is shown in detail in Fig. 2.

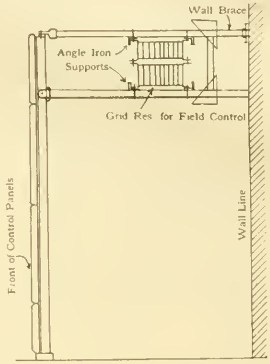

FIG. 8—SECTION OF A CONTROL BOARD

Showing the resistor supported from the wall braces at the rear of the panel.

This second method of installing the connections has several advantages over the first. It eliminates delay in floor construction that might be necessitated by not having at hand sufficient conduit. It facilitates the laying of the conduit, and eliminates difficulties due to mistakes in putting in the wrong size or not a sufficient number. The cost of installing the leads and making the trenches may be more, but this cost is offset by the time and expense which might be incurred in putting in the wrong size or number of conduits, and the elimination of delay in making the floor.

The armature and field leads of the direct-current mill motor and the generator, and the primary and secondary leads of the alternating-current motor for the flywheel set are brought out for external connection under the machines. Therefore, provision must be made in the foundation of each one of these machines for making the external lead connections. If the station has a basement, it is very simple to make this provision. The foundation in this case is made with pits under the armature of each machine where

the leads come out. These pits should be high enough to permit ample space in which to make the cable or strap connections to the machine leads. Enough supports must be provided for supporting the cable or strap. A doorway is made through the foundation walls where the external leads enter. This type of foundation construction was used in the station shown in Fig. 4.

In stations not having a basement, the providing of this pit is not so simple. A manhole must be made, either where the leads enter through the foundation or at some other point, of sufficient dimensions to permit access to the pit. The pit need not be so large, but it should be of ample size to permit a workman room to move around with ease. The station shown in Fig. 2 uses this type of construction.

METHOD OF TERMINATING CONDUITS AT SWITCHBOARD AND CONTROL PANELS

The method of terminating the conduits in the rear of the switchboard and the control panel requires consideration to obtain a neat job. To accomplish this is an essential part of the construction work which cannot be slighted. It is necessary in good construction work that these conduits terminate uniformly in height and in a straight line back of the board. The elbow bends should be embedded in the floor with only the straight part of the conduit extending above. In thick floors or ground floors, it is very easy to keep the elbows embedded, but with thin floors this is impossible. Therefore, to avoid having the elbows extending above the floor, two general schemes have been more or less adapted as standard construction for this work.

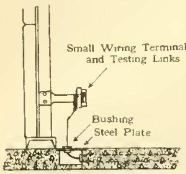

FIG. 9—WIRING TRENCH

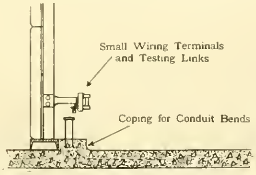

FIG. 10—COPING FOR CONDUIT

The most common method is to provide a coping of sufficient height to cover the elbows, this coping to extend the length of the board. Fig. 10 shows a section through the board with the conduits embedded in a coping extending two inches above the floor. The height of this coping is sufficient only for instrument and control wire conduits up to one inch diameter.

Another method of construction sometimes used is to provide a trench in the rear of the board and extending its entire length. This trench should be about four inches deep and from six to eight inches wide. The conduits to the board terminate in this trench, and no elbows are required. The trench is covered with sheet steel plates having a series of one inch holes drilled in them, which are provided with conduit bushings, as shown in Fig. 9. The cable as they come out of the conduits are pulled up through the holes and connected to the board. In this arrangement no conduit extends above the floor.

CONCLUSION

In reviewing the preceding discussion, one may question why such particular attention should be paid to the selection, design and installation of the equipment and station for a reversing mill motor. This question arises doubtless due to failure to appreciate the importance of this type of mill, with respect to the output of the entire plant. A blooming mill feeds steel for every other mill in the plant. It is through this mill that the ingot, cast direct from the furnace metal, must pass before it can reach the billet, structure, rail, slab, sheet mill, etc., and from these to the various finished products. It is evident, therefore, that if a blooming mill is shut down for any length of time, the output of the plant is decreased thereby. It is in driving this type of mill that the electric motor shows its greatest superiority. The importance of this mill makes advisable every reasonable precaution to guard against its failure to operate continuously. This means not only a reliable motor but a perfect installation. It is just as essential that the auxiliary equipment be reliable as it is for the motor. The failure of some small relay, switch or connection will close the mill down just as quickly as the failure of the motor. Not to realize this important fact is liable to lead to disastrous results. Care in all details is required for a properly designed station, using the best of equipment and most reliable forms of installation and construction.

Electric Furnace Gray Iron

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THE sponsors of the development of any revolutionary innovation which has to do with industrial production processes, almost invariably meet with most tenacious opposition and serious difficulty. The history of the iron and steel industry's development during the past century is largely a chronicle of the fight which men like Bessemer, Siemens, Marten, Tropenas, Hadfield and others waged in securing recognition and adoption of their inventions. Among the radical inventions growing out of the development of the iron and steel making processes, the electric furnace has been by far the most fortunate with respect to the rapidity with which it has come to be recognized as an accepted, reliable and practical melting and refining medium.

The commercially successful electric furnace is less than twenty-five years old; but there are hundreds of them at work in the United States alone, while in European countries like Sweden and Switzerland, where underlying economic conditions are so exceptionally propitious for the electric furnace, the majority of all ferrous melting and even smelting, is carried on with electricity. The electro-metallurgical furnace may then be rightly considered as well established in the metal industries.

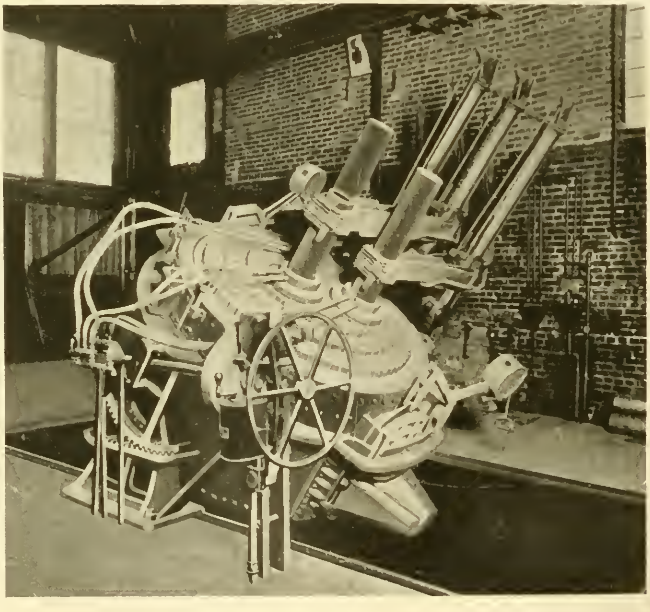

FIG. 1—3000 POUND, THREE ELECTRODE, 'LECTROMELT FURNACE IN THE WORKS OF THE QUEEN CITY FOUNDARY CO., DENVER, COLO.
Producing gray iron castings. The furnace is charged to 6200 pounds.

Its debut was made in the tool and alloy steel fields, where the product had a margin sufficient to withstand the melting cost which was high, due to the inefficiency of the furnace as then designed. Success in these fields, together with increased rapidity of melting and efficiency in furnace design, led to its adoption in the steel casting industry.

Having qualified from the standpoint of quality and also, from the important one of economy, the electric furnace is now establishing itself in the gray iron foundry.

ECONOMIES

The matter of cost is one which presents itself for consideration primarily and is of course a factor of controlling importance in many, if not the majority, of cases. There are few localities in the United States where the direct conversion cost per ton of melting in the electric furnace is not higher than the same figures for cupola operation. By direct conversion cost is meant the cost of one-sixth or one-seventh of a ton of coke, plus blower power, plus direct labor and refractories and melting losses for the cupola; 500 to 550 kw-hr, plus sixteen pounds of carbon electrodes plus labor and refractories and melting loss for the electric furnace; and interest and depreciation or maintenance for both.

With basic prices of $10 coke laid down and power at 1.5 cents per kilowatt-hour, these respective conversion costs have the average of eight to ten dollars for the cupola and twelve to fourteen dollars for the electric furnace under average cost conditions east of the Mississippi River. These figures are purely on a cost competitive basis, taking no cognizance of the advantages of either process, one way or the other, or of conditions prevailing in many locations where coke is extremely high or electric power unusually low.

Thus the savings to accrue from the electric furnace are not usually to be expected or realized in the direct conversion costs, cupola versus electric. There

is, however, a means of actually producing metal in the ladle, ready to pour, with the electric furnace more cheaply than cupola iron in the same condition. This is true as a consequence of the difference in the cost of the raw materials forming the cupola charge and the electric furnace charge. While the conversion cost in the electric is higher, the difference in the cost of charge for the cupola and electric is almost invariably sufficient to more than offset the disparity in melting cost.

A word of explanation is needed here. With the cupola, it is not possible to make good castings from a charge made of one hundred percent scrap; and such grades of scrap as cast iron borings, steel turnings, very light drop forge flashings, punchings, clippings, etc. are considered entirely out of the question as to utilization in cupola mixes. The rapid type electric furnace is; in several sections of the United States;

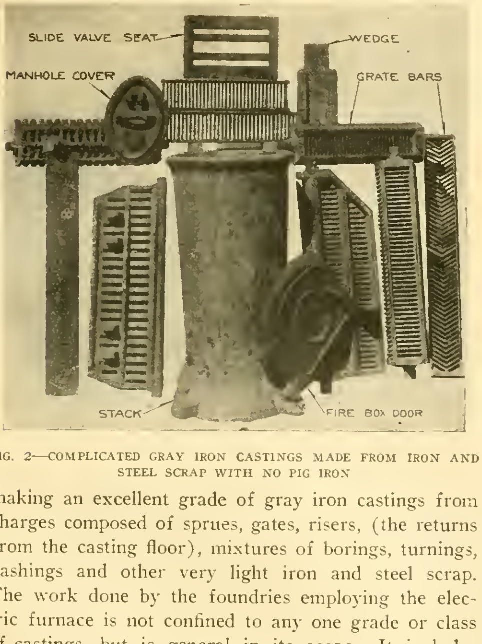

FIG. 2—COMPLICATED GRAY IRON CASTINGS MADE FROM IRON AND STEEL SCRAP WITH NO PIG IRON

making an excellent grade of gray iron castings from charges composed of sprues, gates, risers, (the returns from the casting floor), mixtures of borings, turnings, flashings and other very light iron and steel scrap. The work done by the foundries employing the electric furnace is not confined to any one grade or class of castings, but is general in its scope. It includes very low priced work such as grate bars, cast water pipe and high grade work like piston heads, locomotive cylinders, fine light work such as small valves and automobile piston rings, and special hard, tough iron like chilled rolls and wearing plates. The illustrations give a general idea of the wide varieties of castings produced. The foundry which made the parts shown originally installed the furnace for the purpose of making steel castings, subsequent trials demonstrating it to be economical to shut down their cupola and pour all castings, both iron and steel, from the electric furnace.

COMPARISON OF PROCESSES

It has been a generally held precept in the iron casting industry that "all scrap" mixes were incapable of producing high grade castings; and some purchasers, even at the present time, specify that no scrap shall be used, when purchasing particularly high grade castings. This evokes the question as to the ability of the electric furnace to convert all scrap charges into high grade gray iron castings. With years of experience in cupola foundry work, the man who has "served his time" usually has a deep seated idea that the proposal to manufacture good castings from all scrap charges is preposterous, regardless of final analysis obtained. His experience with the cupola has naturally developed such an attitude as a result, in all probability, of grievous and costly experience. Analysis of the two melting processes clears the question.

When the cupola is prepared for the day's melt a small amount of wood is placed on the hearth and a bed of coke laid on top of this. Alternate layers of coke and iron are then piled in until the charge is completed. When the fire is started and the blast turned on, as the iron becomes heated it melts and drops down onto the hearth. When a sufficient quantity of iron for tapping is collected in the bottom of the shaft, it is drawn off and poured into the flasks. During the melt the iron is continually in close and intimate contact with the coke, ash and fluxes. It is unreasonable to expect that the iron would do otherwise than absorb slag and the impurities of the coke, the chief one of these being sulphur. This happens with unfailing regularity to the consequent detriment of the molten metal. In operation, if the cupola charges have an average sulphur content of 0.05 percent, the metal as tapped will analyze for sulphur 0.07 to 0.11 percent. This is serious enough, but the metal is further in contact with the air blast used in the combustion of the coke. This blast has a decidedly oxidizing effect on the metal and is said to account for the sparkling of the iron when it is tapped, due to inclusions of oxides. It is certainly true that it is possible to oxidize metal by the blast, and metal melted in the cupola and then refined in the electric furnace has different characteristics from the metal as it comes from the cupola. The consequence is that, with the utmost care, iron melted in the cupola is more or less oxidized and has slag and other impurities in it.

The cupola, in so far as definite chemical control of melted iron is concerned, is a hit or miss affair. It is estimated a certain percentage of alloys such as manganese and silicon will be burned out; but it is impossible to predict with regularity what the analysis of the molten metal will be. Definite control of the total carbon and of the graphitic and combined carbon as a function of silicon, manganese and other alloy contents is therefore an impossibility. This is accentuated by the fact that once the iron is melted there is no practical way of correcting deficiencies in the analysis of the molten metal. The iron must then be poured into moulds or pigged, it being a matter of choosing

the lesser of two evils as to which course will be pursued, if the metal is not right. These are inherent deficiencies of the cupola; but it is not the purpose or intention of this article to in any way decry the cupola. It is an old, proven and efficient melting apparatus; and its shortcomings are alluded to only for the purpose of comparison with the electric furnace and explaining why electric gray iron is superior to, and often cheaper than, the cupola product.

In preparing the charge for the electric furnace, material is selected which gives a resultant mixture as close to the specification of the finished metal as possible. The furnace being charged, the electrodes descend on the scrap and the arc forms. From then on the metal is heated and melted by the radiation and direct play of the arcs alone. There is no fuel for the metal to be in contact with, and there is no pick up of sulphur. With the basic furnace, sulphur can be reduced to 0.02 to 0.009 percent with regularity and certainty. No blast is necessary and the furnace is kept sealed as tightly as is practicable. At no time of the heat, unless it is desired, is the metal in contact with an oxidizing atmosphere. If a small amount of coke be thrown on top of the charge, a thoroughly reducing condition of atmosphere is easily maintained in the furnace hearth.

In melting, the metal does not flow down over a bed of coke but collects on the hearth of the furnace as melted and remains "dead." It therefore has no tendency, of a nature comparable to that in the cupola, to absorb extraneous matter.

The comparison of these two melting conditions suffices as an explanation of the superiority of electric gray iron castings over cupola iron. The action of the electric furnace is refining and degasifying during the whole process, whereas cupola action is contaminating and oxidizing for the great majority of the time. The ability to deoxidize and thoroughly scavenge the iron is the only plausible reason for the ability of the electric furnace to make an excellent grade of castings from mixtures of 100 percent scrap, analysis for analysis.

The iron foundryman is coming more and more to realize the desirability and necessity of chemical control. This is partly a result of his own realization of its desirability and wisdom, and is partly the result of the increasing tendency to place contracts on a specification basis. In this way also the electric furnace has the advantage. It was mentioned that there are no means of correcting deficiencies in the molten metal from the cupola. In the electric furnace when melting is completed and the metal is presumably right for tapping, a sample bar can be poured and judged from fracture or an actual analysis can be made. If the metal is deficient in any respect, additions of alloys or reductions of them can be made to re-adjust the analysis and bring it to the particular point desired. The elements of uncertainty are eliminated, even when using mixes composed entirely of miscellaneous scrap.

USE OF STEEL

It is a well established fact that percentages of steel in gray iron charges are of decided influence in closing up the grain structure of gray iron and in making a tough, shock-resisting metal. This use of steel in the cupola is attended by hardness of castings, unless silicon be added, which is usually accomplished by including percentages of high silicon pig in the charge. This is very expensive. In using steel in the electric furnace, the silicon is supplied to the bath in the form of 50 percent ferro-silicon and is attended by practically 100 percent efficiency of absorption. There is never any danger of producing hard iron when using steel in the electric furnace charges. For the purpose of giving the steel the necessary carbon content when used in the electric furnace, small percentages of coke are added with the steel. This is usually in the ratio of about 70 lbs. of coke to the ton of steel in the charge. In melting, the steel absorbs carbon from the

FIG. 3—GRAY IRON PIPE CASTINGS MADE FROM IRON AND STEEL SCRAP WITH NO PIG IRON

coke in proportion to the amount of coke present, the intimacy of the coke-steel content or mixture, the degree of temperature and the time of association. Thus it is practicable to make a most excellent grade of gray iron from charges composed entirely of such materials as steel turnings. One plant located at Livet, France, produced more than 500 000 tons of high strength iron castings by this method during the war. Their charges were composed entirely of steel turnings with small percentages of coke. It is reported that the cost of the metal in the ladle at that plant was about one-half that of cupola melted iron for the same locality.

TEMPERATURE CONTROL

When iron melts in the cupola it rapidly drops to the hearth. For this reason the matter of real superheating in the cupola is an extremely difficult one. It cannot be consistently and regularly achieved. The metal drops away from the heating zone too rapidly to obtain the degree of superheat desired.

The temperature of the electric furnace is only limited by the melting point of the refractory lining. This is much higher than any temperature desired for gray iron, even in the most difficult castings. The electric furnace can make iron of temperatures such as are by no means desirable nor recommended. However, it is also true that temperatures such as are not consistently obtainable in the cupola are desirable in gray iron casting work and contribute to the strength and quality of the castings.

The matter of pouring temperatures has been given thorough investigation; and it has been proven that temperatures from 100 to 150 degrees higher than that usually obtained in cupola melted iron materially improve the strength and grain structure of the metal. A maker of soil pipe reports that besides decided increase in strength, he has also been able to increase the specific gravity of the metal ten percent by the use of the electric furnace. This is a most positive indication of increased fluidity, soundness, tightness, and metallic continuity of the castings.

FIG. 4—LOCOMOTIVE CYLINDER CASTINGS MADE FROM ELECTRIC FURNACE GRAY IRON

The temperature control obtainable with the electric furnace permits these higher temperatures with consistency and regularity. They allow the use of low phosphorus iron for many castings which, when cupola produced, require high phosphorus metal. The sole function of phosphorus in iron is to impart fluidity to the molten metal. This is accomplished at the expense of toughness, strength and fineness of grain. Thin, light sections in castings have required the use of high phosphorus metal in the cupola, but the most delicate and intricate shapes can be and are produced in the electric furnace with very low phosphorus iron. An example of this is the individually-cast piston ring which is being made in the electric furnace with very low phosphorus iron with a loss from cold shuts of less than five percent. These rings are cast so nearly to shape that the finishing done on them is reduced to a minimum.

QUALITY CONSIDERATIONS

There is an increasing demand for a grade of iron so far superior to the metal of ordinary cupola quality that its production is coming to be recognized as essentially an electric furnace process. Reference is had to high pressure steam fittings, and to extremely fine grained, high tensile strength, long wearing iron for locomotive and other cylinders, pistons, valve bodies, gasoline motor cylinders, ammonia cylinders and similar work. The difficulty in producing such grades of castings is largely one of getting an iron which is easily machinable and still absolutely free from blow holes. Sulphur gives molten iron a blowing tendency, especially if not superheated, as well as reducing the machinability. At least three valve body foundries, two locomotive cylinder makers, and three piston ring factories have realized the great advantage of the electric furnace for such work and have installed it. These concerns have not only been able to solve their melting problems but have effected marked cost savings by the regular, judicious use of all-scrap charges.

Electric furnace iron, besides exceptional strength, has decided resistance to impact. This characteristic is an important one, since it really places at the disposal of the designing engineer a new metal to work with. In the design of machines, such as agricultural implements, road machinery, motor cars, tractors, etc., many parts must be specified to be of malleable iron for the purpose of giving them shock and impact resistance; but they often require a very decided amount of rigidity, which the normal cross-section of the part, as cast from malleable iron, would not possess in the degree desired and considered necessary. The designer must consequently increase the section, frequently from 200 to 300 percent of the normal area, for the sole purpose of adding rigidity. This is obviously undesirable and expensive. Electric furnace iron can be used to replace malleable iron in many of these applications with superior results, to say nothing of economy. The designing engineer will thus find a new metal at his disposal for such work and in many instances will be able to replace the expensive malleable iron with the superior grades of electric gray iron produced by the electric furnace.

As an indication of what can regularly be expected from electric furnace iron, one user reports tensile strengths up to 62 000 lbs. for iron made from all scrap charges. Still another reports an average of 5100 lbs. transverse strength with a maximum of 6200 and a minimum of 4000 lbs. The bars tested were taken from 12 successive heats from charges of gray iron borings and axle turnings. An average analysis is given: carbon, 3.20 percent, sulphur 0.05 percent, phosphorus 0.25 percent, manganese 0.70 percent, silicon 2.10 percent. No particular difference in this analysis from ordinary cupola metal exists except that the sulphur is lower than ordinary, due to the absence of sulphur pick-up in the electric furnace and to the dilution with low sulphur steel. The phosphorus is also lower as a result of the latter cause. In each case the "melt down" silicon was approximately 1.25 percent. Sufficient ferrosilicon was then added to bring the analysis to 2.00 to 2.25 percent.

The greatest disadvantage of the electric furnace is the first cost of the installation. Under favorable and proper conditions this is offset by the fact that, if the furnace is kept busy and charges are judiciously selected, the net savings on the cost of iron in the ladle will allow the furnace to pay for itself, usually within a year's time or less. This generally applies to localities with power rates up to 2.5 cents per kw-hr. The electric furnace has a life of from 12 to 25 years with reasonable care.

In selecting a furnace, it is advantageous to adopt a rapid operating furnace just sufficiently large to take care of the foundry's maximum output on a 10, 12 or 24 hour melting basis, with reasonable allowance for expansion. An economical furnace for a gray iron foundry should be capable of making a heat in one hour's time and should be capable of being overloaded 200 to 300 percent for large castings. Conversion costs in the electric furnace are, other things being equal, in general proportion to the amount of time required to complete a furnace cycle, i.e., from tap to tap. Unless this type of operation be contemplated, the figures given in this article would hardly apply. Such a furnace should have a suitable adjustment of voltages for melting and refining rapidly and efficiently.

It is by no means the intention to convey the impression that the electric furnace is going to supplant the cupola everywhere at once. It is beginning to find its field in the gray iron and malleable iron foundries, just as it has already, in large measure, done in the tool steel, rolling mill and steel foundry industries. In doing this it is naturally supplanting some cupolas.

First Reversing Mill Drive in This Country

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Vice-President A. I. & S. E. E.

IN VIEW of the fact that a large number of motor-driven mills have been installed in the last few years, it may be of interest to learn something of the history and development of this type of drive in this country. We have all heard more or less concerning the design and physical layouts of the newer installations. So successful have they been that this type of drive has become generally recognized as standard for reversing mills. The following, therefore, is not given with a view of comparing the first drive of this type with those now being installed, but to give some record of the performance of the first mill of this type in this country, which has been in almost continuous operation since its installation nearly fifteen years ago.

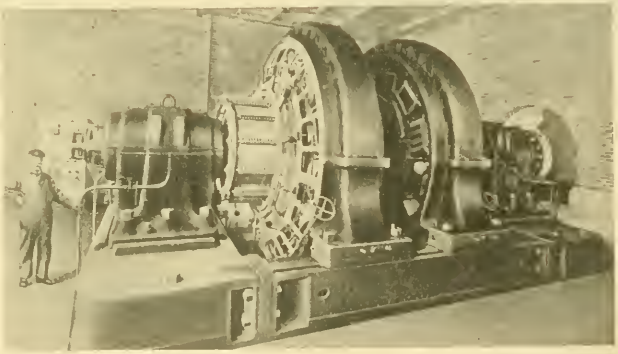

FIG. 1—THE FIRST REVERSING MILL MOTOR INSTALLED IN THIS COUNTRY

The first drives of this type were installed in Europe in 1906. However, about the same time some experiments were carried on by the engineers of the Illinois Steel Company, using a 25 hp, 250 volt, compound-wound motor, driving a 75 hp compound-wound generator, direct connected to a flywheel. A 75 hp compound motor was geared to a small two high roll train, and steel was rolled successfully. The results of this experiment convinced those concerned that a mill drive of this type could be developed. The uniform demand on the power station, together with the small transmission and standby losses, made the proposition very attractive as compared with the steam reversing mill then in service. Equipment for a 30 in. universal plate mill was therefore purchased in 1906, and put in operation in 1907.

The general specifications covering the equipment, which is still in operation today, were as follows:—

Motor-Generator Set—Motor 1300 hp continuous; three-phase, 25 cycle, 375 r.p.m.; generator 2000 kw normal, 6500 kw maximum; voltage 600; weight of flywheel 100 tons.

Roll Motors—Two on one shaft, maximum speed full field 100 r.p.m.; maximum speed weak field 150 r.p.m.; voltage 575; maximum output 8000 hp.

The first steel was rolled in July, 1907. Soon

after the mill was in operation, opportunity was afforded to obtain satisfactory data for such corrections in design as might be necessary, there being practically no such data available at the time the equipment was built.

After a few months of operation, experiments were made which showed that the commutation on the generator could be somewhat improved by increasing the compensating winding. This additional winding was installed during the latter part of 1909. Installation of this additional winding was the only change in the original design which was found necessary. In 1917 a liquid type slip regulator was installed to take the place of the step-by-step type originally furnished. This was done not only to improve the operation from the standpoint of uniform power station demand, but also to provide additional space for substation equipment, the liquid type regulator being very compact as compared with the grid resistance originally installed.

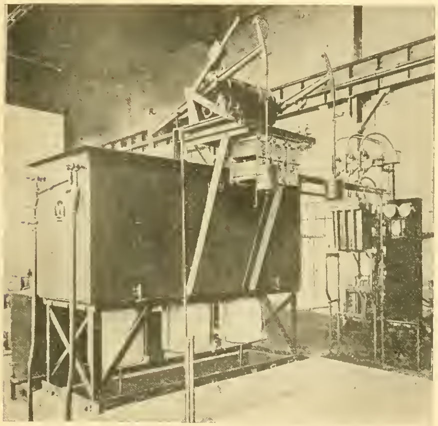

FIG. 2—LIQUID TYPE SLIP REGULATOR
Installed to replace notching-in relay control.

Curves of the alternating-current motor while operat- with the original regulator, and also while operating with the liquid type regulator, are given in Fig. 3.

The following is a detailed summary of the major delays between 1907 and 1921:

Nov. 10th, 1907, mill was shut down for one week to correct generator armature cross connection.

Oct. 14th, 1908, mill shut down to try out spare armature which had been purchased.

Sept. 12th, 1909, changed generator armature on account of grounded coils.

Oct. 24th, 1909, trouble with generator armature bars coming unsoldered. Armature changed.

All of the above delays occurred before the additional compensating winding was installed. No further delays were experienced until 1911, when a delay of a few hours was caused by slight short-circuit on the commutator segments on one of the roll motors. In 1913 the mill was down for approximately 72 hours due to grounded roll motor coil. In 1917 the generator armature was changed on account of a ground. The sum total of all these delays, including those which might be considered as occurring during the development period, is approximately 525 hours. The entire operating time since the equipment was installed, neglecting Sundays, represents something over 100,000 hours, showing that delay caused by the failure of the electrical equipment was slightly less than one half of one percent of the time, and the major portion of this delay occurred within the first three years of operation.

It may be of interest to know something of the physical condition of this equipment at the present time. The original winding on the roll motors is still in service. The original commutators on both the roll motors and generator are in service, only about 1/16 in. wear being apparent on the roll motors since they were installed. The generator commutators show a reduction of about 1/16 in. every five years due to wear and dressing. The original bearings are still in service. Some wear on the motor-generator set bearings was noticeable at the end of ten years. At this time a spare set of bearings was purchased to guarantee against bearing failure, knowing that they would be required eventually due to ordinary wear. These bearings have never been installed, very little wear hav-

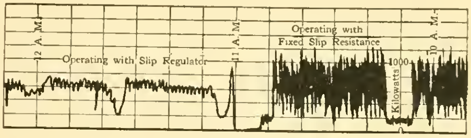

FIG. 3—POWER INPUT TO FLYWHEEL SET FOR THIRTY INCH UNIVERSAL PLATE MILL

ing occurred during the last five years due to an improved oscillating device having been installed. Since the installation of this equipment something over 1 100 000 tons of steel have been rolled.

During the last few years the equipment has not been favored in any way fearing a breakdown due to the deterioration of the winding through age. As a matter of interest the tonnage rolled during the year 1920 was the maximum ever rolled, and was nearly 20 percent greater than that rolled during any year of the first ten years of operation.

The experience outlined above shows that after fifteen years of service no definite conclusion can be formed as to the life of a winding on this class of equipment. Particular care has always been given toward keeping the winding free from oil, etc., which is detrimental to the life of any winding. The entire installation has been cleaned and painted regularly, the stators being moved over so that both stators and rotors could be given a good coat of paint. Time has always been found to do this kind of work during almost any normal year, and we have reason to believe that the small expense thus incurred has added considerably to the life of the equipment.

Electrical Transmission vs. Coal Transportation

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ELECTRIC transmission lines have hitherto been built chiefly in connection with hydro-electric plants, as the water powers are generally far distant from the cities where the energy is marketed.

Their successful operation has raised the question as to whether it is possible also to locate steam power plants at the coal mines, and transmit the power over electric transmission lines to the ultimate market, thereby saving the expense of shipping the coal and the possibility of shortage of coal caused by labor troubles on the railroad.

In general, the location of a power plant at a mine will insure freedom from the effects of a coal strike or a railroad strike. In the case of abnormal conditions, such as the recent war period, it will result in securing a uniform grade of coal at a reasonable cost.

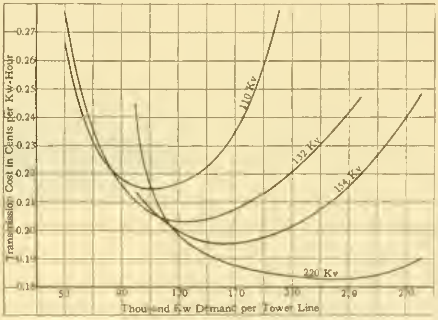

FIG. 1— TRANSMISSION COSTS FOR 50 PERCENT USE FACTOR

In considering the location of a plant at a mine, in addition to the fuel supply, an even more vital consideration is whether adequate water is available for condensing purposes. A modern steam turbine plant requires about 1.5 gallons or 0.2 cu. ft. per minute per kilowatt of station capacity, and in the coal areas, with the exception of the Pittsburgh district, there are few sites where the amount of water is sufficient for plants of 100 000 kw and larger.

Real estate near a mine can generally be secured at a lower cost than in a large city, and the power plant structure can usually be less pretentious from the architectural standpoint. The main question, however, is whether the cost of transmitting electrical energy is less than the cost of the rail shipment of coal. The cost of transmitting electrical energy depends on many factors, such as the amount of power transmitted, the load factor, and the amount of spare equipment provided for emergency use. The latter factor will be based on the attitude of the operating companies towards continuity of service, the type of country traversed by the transmission lines and the character of the load served.

Transmission lines may have interruptions due to broken insulators, lightning, high winds and storms, and to guard against these failures requires additional transmission circuits or else standby generating stations at the load end of the line. A recent A. I. E. E. paper* discusses the service that can be expected from long distance transmission lines and arrives at the conclusion that "two tower lines, each supporting two circuits, each tower line with its circuits being capable in emergency of transmitting the entire load, would reasonably insure continuity of service of the character demanded by the metropolitan district of New York City."

To determine the cost of electric transmission, a large number of items have to be considered, many of

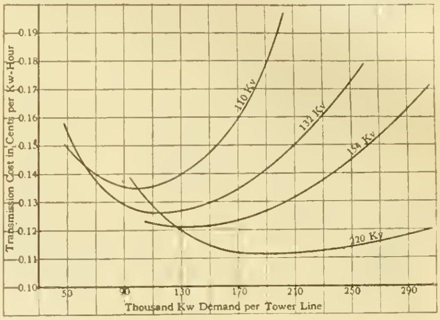

FIG. 2—TRANSMISSION COSTS FOR 100 PERCENT USE FACTOR

which will depend on local conditions, so that this article will indicate only in general terms the method to be followed.

In calculating the transmission cost, the following formula has been used. The transmission cost per kilowatt-hour delivered =

$$\frac{A + B + C + D + E + F + G}{Kw\text{-}Hr.\ delivered}$$

Where $A =$ The fixed charges on the step-up transformer substation,
$B =$ The fixed charges on the transmission lines,
$C =$ The fixed charges on the step-down transformer stations,
$D =$ The fixed charges on the synchronous condensers necessary, together with switching equipment and transformers.
$E =$ The fixed charges on the additional generating capacity to compensate for the losses,
$F =$ The cost of the yearly losses in transmission lines, substations, and condensers,
$G =$ The yearly operating cost of substations and transmission lines.

There are various details connected with these items which should be further discussed.

*"Long-Distance Transmission of Electric Energy" by L. E. Imlay, in the JOURNAL A. I. E. E., June 1921, p. 516.

If a plant is built at the load center, the extent of the distribution network may be such that it cannot be served at the generator voltage, and so a step-up transformer substation is necessary with various outgoing feeders. The cost of this substation could be very properly deducted from the main step-down substation in the transmission scheme.

TABLE I—220 K V TRANSMISSION

Receiver load in k w.	100 000	150 000	200 000	250 000	300 000
Condenser Capacity for 100 % P. F. receiver load to Maintain receiver voltage 200 000.	10 000 lag	18 000 lag	18 000	18 000	52 000
Condenser capacity with 85% receiver P. F. to maintain receiver voltage 200 000	58 000	87 000	144 000	191 000	256 000
Condenser losses in k w.	1800	2400	3600	5400	7200
Line losses in k w.	1568	3458	5800	9028	13 372
Transformer losses in k w.	2968	4572	5972	7340	8640
Total losses	6336	10 370	15 472	21 760	29 200
Efficiency percent	94	93.5	92.8	92	91
Generator power-factor percent	99.5	99.5	97.3	97.3	96.6

On transmission lines, it is now customary to provide sufficient synchronous condenser capacity to maintain a constant receiver voltage. The capacity required is generally in excess of that necessary to in the receiver distributing network, if the synchron- that the power-factor is corrected to unity will result in better voltage regulation and reduced copper losses in the receiver distributing network, if the synchronous condensers are located at various points on the receiver network.

TABLE II.—154 K V TRANSMISSION

Receiver Load in k w.	100 000	150 000	200 000	250 000	300 000
Condenser capacity for 100% receiver power factor	6000	14 000	32 000	80 000	146 000
Condenser capacity with 85% receiver power-factor.	74 000	119 000	168 000	253 000	350 000
Condenser losses	1800	3600	5400	7200	10 800
Line losses	3200	6640	12 400	20 920	34 740
Transformer losses	2620	4094	5740	7400	8600
Total losses	7620	14 334	23 540	35 520	54 140
Efficiency, percent.	92.9	91.3	89.5	87.5	84.7
Generator power-factor, percent.	94.8	95.8	95.5	93.5	91.5

If, however, the condensers are located in the main step-down substation, all the losses incident to a lagging power-factor are still present in the receiver network. It may, therefore, be argued that, in the former case, all synchronous condenser capacity should not be charged against the transmission scheme or, expressed in another way, the transmission scheme should be credited with whatever reduction of losses and increased kilowatt capacity is gained in the receiver network due to the use of synchronous condensers.

The losses in transformers, condensers and transmission lines will vary with the load, so that in order to calculate the yearly losses, it is necessary to know the load and the time interval that the load is on. As the load factor does not give this data without the addition of a load curve, it is advisable to use some other factor for general calculations. A convenient expression is the term "use-factor" which can be defined as follows: For any given demand, a 50 percent use-factor means the use of this demand for 50 percent of the time, and the losses are taken as corresponding to the loss at this demand for half the time. Fixed charges may be taken as follows:—

Transmission lines .... 12 percent
Power stations and substations .... 14 percent

Standard voltages for transmission purposes are 110 000, 132 000, 154 000, and 220 000 volts. These voltages are the voltages at the generating station end

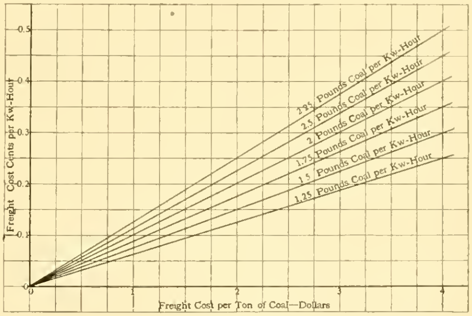

FIG. 3—COSTS PER KW-HR FOR SHIPPING COAL BY FREIGHT

and the voltages at the receiver end are commonly taken as 100 000, 120 000, 140 000 and 200 000.

The procedure to be followed in making a detail study of the cost of transmission is as follows:

1—Calculate the performance of the transmission line and determine the necessary condenser capacity required to transmit the load.

2—For various loads, calculate the losses in transmission lines, transformers and synchronous condensers.

3—Estimate the cost of substations, transmission lines, synchronous condenser and the additional generating plant to supply the losses.

4—Determine the fixed charges, the cost of yearly losses, cost of operation, and tabulate the information for various demands and use-factors.

5—Calculate by the formula the cost of transmission per kw-hour delivered.

As an example typical of the general method, consider a double circuit tower line, 90 miles long, with conductors of 500 000 circ. mil copper. Tables I to IV give the performance of this line for the different voltages, and the curves in Figs. 1 and 2 show the cost of transmission in cents per kw-hr. for use factors of 50 and 100 percent. A spare double circuit transmission line has been included to secure a high degree of service. The costs of lines and substations are

based on present day costs and include all equipment necessary, real estate, buildings and erection of all equipment. A spare transformer has been included in each substation, also spare parts for switches, and a set of coils for synchronous condensers. The operating costs have been based on the results obtained from modern transmission systems. In determining the cost of the yearly losses, the price of a kilowatt-hour has been assumed to be 0.5 cent per kw-hour. Tables I to IV are based on two circuits of a double circuit tower line. The spare double circuit tower line has been assumed not to carry any load in calculating the performance given in the tables, though under actual conditions all four circuits would be used to carry load. In Figs. 1 and 2, the demand includes the two circuits of one tower line.

In basing any conclusions on the results shown in Figs. 1 and 2, it should be remembered that they show the solution of a particular problem and the same size conductor has been used for all four voltages. The curves clearly illustrate that for minimum transmission cost, the larger the block of power to be transmitted the higher the transmission voltage.

TABLE III.—132 K V TRANSMISSION

Receiver load in k w.	50 000	100 000	150 000	200 000	250 000
Condenser capacity 100% receiver power-factor.	8000 lag	10 000	36 000	84 000	110 000
Condenser capacity 85% receiver power-factor.	26 000	78 000	144 000	220 000	284 000
Condenser loss	730	2400	3600	5400	7200
Line losses	1036	4000	9680	18 900	30 200
Transformer losses	1492	2570	3720	5280	6720
Total losses	3258	8970	17 000	29 580	44 120
Efficiency, per cent.	94.0	92.2	89.8	87.1	85.[illegible]
Generator power-factor, percent.	93.[illegible]	94.5	95.5	95.5	91.2

Fig. 3 shows the cost of rail shipment for varying freight rates and fuel economies. Modern stations have operating records from 1.4 to 1.6 pounds of coal per kw-hour based on coal of calorific value of 13 500 B.t.u. per pound.

As will be seen from the curves, the cost of transmission depends largely on the use factor. At 50 percent use factor, for demands per tower line varying from 80 000 to 300 000 kw, the cost of transmission will only vary from 0.22 to 0.18 cent per kw-hr. and for 100 percent use factor from 0.14 to 0.12 cent. With a modern plant burning 1.5 lbs. of coal per kw-hr. and $2.00 per ton freight rate, the cost of rail shipment is 0.15 cent per kw-hr.

If the mouth of mine plant and transmission system is built as an addition to an existing plant to meet the increased demands, it may be possible to operate the modern plant and the transmission system at a high use factor, holding the local plant for peak loads and emergency conditions. This is especially true when a number of plants are interconnected and are available for service in case of emergency. Actual operating records show that large turbine units, condensers, transformers and transmission lines can be operated for long periods at full load, and thus maximum returns can be gained from the investment.

TABLE IV.—110 K V TRANSMISSION

Receiver load in k w.	50 000	100 000	150 000	200 000
Condenser capacity 100% receiver power-factor.	0	20 000	50 000	132 000
Condenser capacity 85% receiver power-factor	34 000	88 000	155 000	205 000
Condenser losses	840	2600	3600	7200
Line losses	1364	6020	14 360	32 960
Transformer losses	1360	2340	3632	4900
Total losses	3564	10 960	21 600	45 060
Efficiency percent	93.4	90.1	87.4	81.6
Generator power-factor percent	98.5	97.	94.5	90.9

Under these conditions, the cost of transmission is low which combined with the indirect advantages mentioned earlier, makes the transmission scheme very attractive. As a further advantage to the country at large, a large number of railroad cars and their attendant train crews would be released for other service.

In the Pittsburgh district, there are large coal deposits along the rivers, so that both coal and water are available in almost unlimited quantities. Away from the main rivers, however, water is not available for large plants, so that extensive transmission systems are developing, supplying large amounts of cheap power to cities where the water conditions do not permit the building of large plants.

Insulation for Steel Mill Motors

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IN addition to demanding more from a motor in rolling mill service than is expected in the average application, the rolling mill presents exceptionally severe operating conditions. The windings become covered with mill dust which is more or less conducting. This dust tends to work into the small crevices to such an extent as to puncture the insulation. Many of the motors are subject to vibration from the load which they drive. The vibration chafes the insulation and accelerates failures caused by dust or by temperatures above the safe limit. The motors may even be subject to salt scale and moisture which becomes chemically active and injurious to the insulation. The motors which operate over the furnaces or near them are frequently as hot at no load as an ordinary motor is supposed to be at full load. Thus these motors require insulation which will safely stand very high temperatures.

The insulation which successfully withstands the severe operating conditions and fully meets the requirements and expectations must be of the best. It must not only be good when it is new, but must have life that will preserve it through severe operating conditions. This requires high grade, materials, their correct combination and grouping, adequate methods of applying and of protecting them. Not only must the insulation conform to the electrical and mechanical features of the design, but the electrical and the mechanical features must be made to conform to the requirements of good insulation.

Insulation may be likened to the arteries and veins of the human body through which the life blood is carried to all parts of the body. In like manner the insulation directs the path of the electric current through the proper circuits. The protection which the insulation must offer can be divided into three classes.

1—To protect against a short-circuit between adjacent turns or other parts of the same coil; that is, on the inside of the coil.

2—To protect against the ground strain in the slots or other parts in contact with the core. There is a continuous dielectric strain from the winding to ground.

3—To protect one circuit from another between which there is possibly full rated voltage, such as from one phase to another on polyphase alternating-current motors and from the positive side of the circuit to the negative side on direct-current circuits.

INSULATION ON STATOR WINDINGS OF LARGE ALTERNATING CURRENT MILL MOTORS

The following methods of insulating to protect against short-circuits within a coil represent the best modern practice. On induction motors for rolling mills the stator winding is composed of diamond shaped coils. The conductors are rectangular shaped and cotton covered. The coil is made to the correct shape so that it will fit into the slots, and so that the voltage of one turn of wire is the maximum voltage between any two wires lying side by side in the coil. This makes the dielectric strain on the insulation inside of the coil a minimum. The rectangular conductors keep the mechanical strain of the wires resting or pressing against the adjoining wires to a minimum value by having a flat surface resting against a flat surface.

The coil is then treated in a compound which causes each cotton-covered conductor to be completely surrounded with a homogeneous compound, of high dielectric strength, that resists moisture and high temperature and thereby adds greatly to the life and safety of the insulation. On the larger motors this is done by placing them in an impregnating tank. The coils are dried by raising the temperature in the tank and then creating a vacuum to remove the last traces of moisture and to cause the cotton covering on the wires to absorb the compound readily. The compound is then forced into the tank and into the coils under hydraulic pressure.

The insulation on the slot portion of the coil must be the best possible, as it must stand the full dielectric strain to ground and also resist the mechanical and electrical strains. On a three-phase circuit, this strain is equal to the voltage between terminals divided by 1.73, if no part of the winding is grounded. If one side of the line circuit becomes grounded, the strain on the slot insulation of each coil becomes equal to the terminal voltage. This insulation must have high dielectric strength to withstand the ground strain and must have small dielectric loss. It must have sufficient mechanical strength to stand the twisting of placing the last throw of coils into the slots when winding, and to resist the strains due to vibration, accidents and short-circuits.

The slot portion is insulated with a wrapper which is a combination of materials that will best serve this purpose. This wrapper is usually composed of a number of layers of mica splittings which are built up with a special mica bond for sticking them together and on a high grade paper. Mica is the best insulation known. It has a high dielectric strength. It is the best for resisting high temperature. Its resistance to crushing is very high. It is the best material for resisting moisture as it is practically non-absorbent. It is resilient and therefore acts as a spring in keeping coils tight in the slot to take up any shrinkage in the other materials. The paper acts as the backing for the built up mica and furnishes the required toughness as well as increased dielectric strength. The paper is chosen on the basis of toughness and dielectric strength.

The end portions of the coil especially are subject to the action of the gritty mill dust and moisture, and to any vibration that may exist. The ends are therefore insulated in such a way as to provide maximum insurance against short-circuits within the coil and from coil to coil and between phases under the above conditions. The thorough impregnation of the conductors in the coil protects them one from another. The taping of the end portions of the coil with layers of a high-grade treated tape followed by a layer of cotton tape which is later thoroughly filled with varnish, effectively furnishes the necessary protection. Each layer of tape is half overlapped. Each layer of treated tape is thoroughly brushed with a good insulating varnish which makes the insulation more compact as well as improves the dielectric strength and seals against dust penetration. The treated tape has very high dielectric strength and is the best material for insulating the end portions.

The outside of the coil is completely taped with a layer of cotton tape which is half overlapped on the end portions and has the edges butted over the slot portion. This tape has several functions to perform.

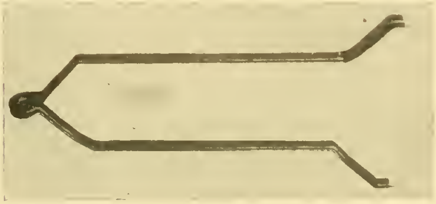

FIG. 1—A TYPICAL ROTOR COIL FORMED TO EXACT SHAPE AND COMPLETELY INSULATED BEFORE PLACING IN SLOT

It holds firmly in place the main insulation which is depended upon for the dielectric strength and also protects this insulation from mechanical damage. It is then given thorough varnish treatments for further protection against moisture and gritty dust. These varnish treatments add to the dielectric strength and increase the life of the tape, and also facilitate the conduction of heat from the coils. They include drying, dipping, draining and baking, these operations being repeated until the required number of coats have been applied.

Before placing the coils, the slots are smoothed off by filing so as to remove any burrs or rough spots. Slot cells are then placed in the slots so as to add additional mechanical protection for the insulation on the coils. A very tough paper is used for this purpose so that the laminations will not cut their way into the coil insulation when the winding is subjected to mechanical stresses. As this paper cell serves the same purpose while inserting the coils into the slots, it is dipped in paraffine to further facilitate this process.

The connections from one coil to another and from one group of coils to the others are usually insulated by taping with layers of treated tape and cotton tape as used on the ends of the coils. In other cases, heavy rubber insulated cables are used. These connections must be roped together and be well braced.

The individual conductors in a coil can readily be protected from each other so as not to chafe if the motor is subject to vibration. However, the coil ends must be securely braced so there is no chafing of the outside coil insulation. Each coil is therefore securely roped to an insulated welded steel supporting ring, which is braced by arms fastened to the end plates so as to brace the whole winding as a unit.

After winding all coils into the slots and completing all of the connections, two or more coats of a good baking varnish are applied to the complete winding. This fills up the insulation on the connections and seals up the very small crevices between coils into which gritty dust or moisture might accumulate. It adds further strength mechanically and dielectrically. Records show that varnish dipping of complete windings may more than double the life of the windings.

FIG. B—SECTION THROUGH ROTOR COIL AND SLOT

ROTOR WINDINGS OF LARGE ALTERNATING-CURRENT MILL MOTORS

It is desirable from the standpoint of performance of the motor to use partially closed slot construction on the rotor. It is also very desirable to have coils which are completely formed to shape and completely insulated before placing them in the slots. Such coils make winding, rewinding or repairing quite simple. That is, all of the advantages of an open slot formed coil are wanted for a slot which is made partially closed or with an over-hung tip for its great electrical advantages.

This is accomplished by the type of coil shown in Figs. 1 and 2, and by the type of slot shown in Fig. 2. Each coil is divided into two units side by side, each of which is completely insulated to stand the total dielectrical strains, and the slot opening is made sufficiently large for one unit. The slot portions of each of these rotor coil straps are insulated with the same high-grade paper and mica wrapper that is used on the stator coils. The end portion of each strap is taped with layers of treated tape cut on the bias. A layer of cotton tape

is taped over the outside of each strap, the tape being half overlapped on the end portions and the edges butted on the slot portion. The coils are then given a number of thorough treatments of varnish to protect against moisture and gritty dust. Each treatment in varnish always includes drying, dipping, draining and baking. The drying is done at a temperature slightly above the boiling point of water to drive out the moisture and so that the varnish will be thoroughly absorbed. The dipping is done while the coil is hot. The baking is continued until the varnish is thoroughly baked. The slots are filed so as to remove any burrs or rough spots. Tough paper cells are placed into the slots which protect the coil insulation from the laminations.

The connections on the end windings from coil to coil and from one group to another, of a rotor winding requires careful attention. On account of their shape, tape alone is not sufficient. Therefore, caps are sewed from heavy cotton cloth into a shape that fits snugly over each connector. Each cap is then dipped in varnish, drained and dried in a heater until it has received three coats. A number of caps are used over each connector. After putting each cap in place, it is held by tape in such a manner that conducting dust cannot enter and form a path from one connector to another. Treated tape is used for tapping over the caps on all except the outside one on which cotton tape is applied. This layer of cotton tape and the complete insulation joint is thoroughly filled with varnish when the completed winding is given two varnish treatments.

The bracing of the rotor winding and connections is very important because there must not be the slightest movement of any part that would eventually chafe through the insulation. The gritty dust greatly accelerates the effect of chafing. Strong, well insulatated coil supports are therefore used under both ends of the windings. The bottom layer of the winding rests firmly on the supports. The top layer of the winding is separated from the bottom winding by heavy treated duck and presses down firmly on it. A substantial steel band well insulated from the coils is placed over them. The complete winding is thereby securely clamped between the coil supports and the banding wire. The leads and connections are held tightly in cleats at which places the insulation is further protected by additional insulation to withstand the tight clamping.

After winding all coils into the slots and completing all of the connections and banding, two coats of a good baking varnish are applied to the complete rotor winding the same as is done to the stator winding. This adds to the desired rigidity of the winding as well as filling up all crevices to protect against the moisture and the gritty dust, and thereby adds greatly to the life of the winding.

MILL MOTOR ARMATURES FOR VERY HIGH OPERATING TEMPERATURES

In some motor applications the motors operate where the temperature is high. They may be hot without any rise in temperature in the windings themselves. When operating at the average load the temperature of the windings are therefore much higher than is safe for the ordinary insulation known as Class A in the rules of the American Institute of Electrical Engineers. Class A insulation allows a hot spot temperature in the windings not to exceed 105 degrees C.

These very high temperatures would disintegrate the ordinary organic insulating materials such as papers, cotton and other fibrous materials used in Class A insulation. Temperatures above 105 degrees C cause the organic materials to shrink and become brittle and the materials will eventually carbonize if the temperature is sufficiently high. If the insulation becomes brittle it will probably fail mechanically by cracking open when the armature is subject to a severe mechanical strain, such as a quick start or a quick stop, or some jarring action. If the insulation shrinks so as to allow a movement of the coils, only a small amount of brittleness is required to crack the insulation. It is, therefore, not necessary that the material carbonize to cause failure. High dielectric strength alone is not a protection in such cases. The insulation requirements of the armatures are very severe because the effects of the rapidly changing centrifugal speeds are added to the vibration and jolts due to the particular application.

The insulation used for these applications is composed of mica and asbestos with the minimum amount of cotton and fibrous paper materials used as binders or supporting structures. If the conductors are small or medium size, they have a covering of asbestos. The larger size conductors are insulated with mica applied in the form of tape. A paper and mica wrapper is used for insulating the slot portion of the armature coils. A layer of asbestos tape is capped over the outside of the complete armature coil.

The method of making the coils and winding them into the slots has much to do with the successful operation and life of the insulation. That is, all parts of the coils and windings must be compact. Even with the best quality of insulation and regardless of the quantity, the winding must have this compactness, as otherwise the coil would soon become loose in the slot or on the ends.

The method of making coils for this service is to hot press the coil before applying the insulation and then hot press them again after applying the insulation. If there is space for a filler, mica or micarta plate which stands a high temperature is used. By these methods there will be no small air pocket to be crushed out in service or any excess material to carbonize that might cause looseness which would be followed by failure.

FIELD COILS FOR HIGH TEMPERATURE OPERATIONS

The field coils of direct-current mill motors, although stationary are subject to considerable vibration and mechanical stresses. The strains occurring on motors operating at temperatures of 125 degrees C. are too severe for the ordinary fibrous materials. If the conductors are small, asbestos insulated conductors are used. If the conductors are medium or large size, strips of sheet asbestos are used as a separating medium, with the bends specially reinforced. The places where the leads leave the coil or cross the coil are also specially reinforced. The coils are next given a thorough treatment in an insulating compound after drying. The coils are then insulated by applying a heavy insulation composed of cloth and mica, and paper and mica, with the minimum amount of the fibrous materials. The fact that mica is practically incompressible and retains its high dielectric strength even at high temperatures makes it a valuable insulation for this application. Each coil is taped overall with a layer of heavy asbestos tape whose mechanical strength is practically unaffected at temperatures of several hundred degrees C. The insulated coil is then thoroughly treated in varnish.

MILL MOTOR COMMUTATORS

In direct-current machines, the commutators are regarded as the part most susceptible to trouble. Only the best insulation can be considered for the mill motor commutators because a failure usually causes great inconvenience, delay and expense. A failure in the commutator may also be the cause of short-circuits in the winding which may necessitate the rewinding of the complete armature.

Amber mica is used between the bars, and the V-rings are made of moulded white mica. Mica is the only satisfactory insulation for these items. The portions of the V-rings which project beyond the bars are protected with tape, thoroughly filled with coats of thin varnish. This makes a surface which is easy to keep free from the conducting dust.

INSULATION TESTS FOR ALL MOTORS

The last operation on the motors before they are ready for service is an insulation test applied between the windings and frame for one minute with a voltage equal to twice the terminal voltage plus 1000 or greater.

Reducing Mechanical Difficulties With Motor-Driven Applications

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MANY of the difficulties encountered in motor applications are mechanical and not electrical. Motors as applied to various drives may be classified under four divisions, depending upon the method of driving the load:—

1—Belted
2—Geared
3—Chain driven
4—Direct connected

A further classification may be made according to the character of the load under two heads:

1—Cushioned loads
2—Uncushioned loads

A "cushioned" load is such as a radial blower fan, where the elastic characteristics of the air do not offer any forced shocks or impacts to the driving motor. Where shocks or impacts are encountered as in driving ore crushers or punching machines, the load is said to be "uncushioned."

In the design of machines to meet certain requirements, the parts are proportioned to meet the known conditions to which the machine will be subjected. This does not allow for extreme or exceptional service which they are often forced to perform. The machines should not be required to operate for any length of time against conditions that are detrimental, but which unfortunately are continually arising in actual practice. It is surprising to observe the misuse of electric motors on various applications through one cause or another, such as misalignment of parts, sprung shafts, incorrectly cut gear teeth and other mechanical deficiencies which may be due to faulty machining. Additional factors which may eventually cause trouble are lack of proper lubrication of bearings and gears, and failure to tighten holding down bolts and other parts liable to become loose during operation. Frequently, weak and frail foundations cause vibrations or even settling, resulting in excessive stresses which soon cause the machine to fail.

The designer should provide an ample proportion of parts; safe bearing pressures, oil reservoirs of sufficient capacity to provide radiation and conduction of the heat energy caused by friction under all conditions of normal loading. Under conditions of misalignment, various stresses are magnified and the pressures are in turn increased, with a proportional increase of friction heat. If this condition continues, frequent attention must be given to renewing of the lubricant to prevent seizing of the journals. When shafts are refinished there must be a reduction of journal size which has a very distinct disadvantage, as standard bearings are then not interchangeable and require additional labor and expense in rebabbitting of the bearing shell.

In geared applications, shaft deflections due to peak loads have caused grinding out of journals. The

shafts should be so proportioned to take care of such peak loads as the machine may be called upon to perform. Recently, the bearings of direct-connected grinder motors wore out in a very short time, because the bearings were not properly protected against dust from the emery wheel which entered the bearings and scored the journal. The remedy was the addition of felt washers for the exclusion of the dust. Suction fans are often installed to carry away the emery dislodged from the wheel. This has two distinct advantages, as it controls the path of the emery dust and also prevents injury to the workman from the promiscuous flying of dust.

In a rolling mill application, the motors were necessarily placed in proximity to hot metal. This required forced ventilation to maintain the rated output, which was accomplished by means of an exter-

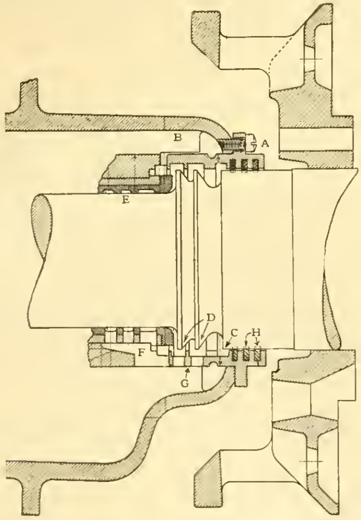


FIG. 1—PREVENTION OF OIL LEAKAGE

Revolving parts rotating at high speed set up a blower action, creating a partial vacuum at the point *A*. Atmospheric pressure within bearing housing *B* tends to produce a flow of air from within the bearing housing to point *A* through the clearance space between the bearing housing bore and the shaft at *C*, which will carry with it any oil thrown off by oil throwers *D* and still adhering to the shaft at the restricted passage *C*. Where the partial vacuum at *A* exceeds one-half inch of water the ordinary dust shield, consisting of an annular felt washer bearing on the shaft and fastened against the end of the bearing housing by another washer of sheet steel, is no longer effective in preventing leakage of oil. Other measures then become necessary. Annular grooves *E* are provided in the bearing, drained by holes *F*, to remove the surplus oil from the bearing before it reaches the oil throwers *D*. In addition, oil catcher *G* and the three felt rings *H* in their annular grooves form an effective seal against the passage of the small quantity of oil still remaining on the shaft at point *C*.

nal blower, the air playing directly upon the bearings and in a direction parallel to the shaft. Trouble was experienced from this installation due to the fact that the air forced the oil along the shaft and out of the bearing housing, where centrifugal force threw it into the air currents, which in turn deposited oil throughout the machine. A change in the direction of the air current and the introduction of suitable baffle plates remedied this trouble. It is apparent that, in the case of such applications, provision should be made when selecting the motor, by using a different method of lubrication, such as grease or waste packed bearings non-fluid lubricants, etc. This instance demonstrates the importance of making a close study of the actual application before selecting the motor.

In another instance, a motor was direct connected to a high-speed fan, which set up considerable suction, drawing the oil out of the housing and into the windings. In this case the bearing cap was tapped for an air pipe which communicated with the outside air, thus by-passing an air current which equalized the pressure within and without the bearing. Such cases may also be taken care of by adding an oil shield on the inside of the bearing housing, which likewise establishes a by-pass for the air, allowing the outside air

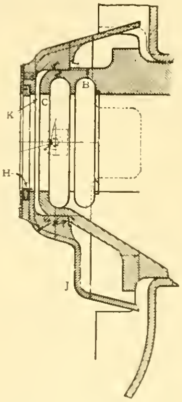


FIG. 2— PREVENTION OF OIL LEAKAGE

An oil deflector *J* is attached to the end of the bearing housing. By the use of this device a chamber *K*, communicating with the external atmosphere, is formed just outside the bearing housing. The air in this chamber will be at atmospheric pressure; consequently there will be no tendency for any flow of a current of air from the interior of the housing. Any leakage of air between the felt washer *H* and shaft will be supplied through chamber *K* and not from the interior of the bearing housing *B*.

to enter the machine instead of drawing it through the housing, thus eliminating the leakage of oil.

Frequently the oil level is too high, covering up the cored holes which communicate between the oil chambers inside the housing; a vacuum is then formed in the chamber next to the inside of the machine, due to the blowers on the rotor, which causes the oil to overthrow and be thrown into the windings. The remedy is a lower oil level or a duct in the bearing cap which will establish communication between the oil chambers and equalize the air pressure.

The correct cutting of oil grooves is an important feature. A case developed where the bearings had been replaced by a millwright and the grooves did not communicate properly with the slot at the oil ring, nor

were they carried out far enough to povide lubricant at the end of the journal. This caused heating of the bearings, and the rapid expansion of the metal due to this frictional heating cracked the housing shell. Replacing this bearing by one which had grooves cut within 3/16 in. of the annular groove at the end of the bearing, and also having grooves well connected with the slot at the oil rings, provided a prolific flow of oil and remedied this trouble.

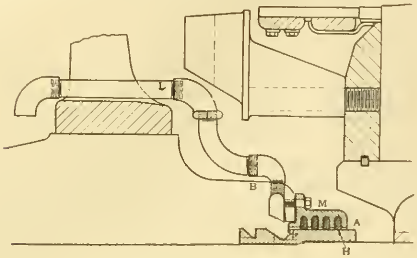


FIG. 3—PREVENTION OF OIL LEAKAGE

In this scheme atmospheric air is introduced by pipe *L* just within the bearing housing *B* thus supplying with air, free from oil particles, any small leakage through the heavily washer seal *M*.

Occasionally a change in the composition of babbitt metals is a remedy for galling of bearings. For example, a 150 hp 1200 r.p.m. motor, equipped with a 4 by 10 in. journal and a 16 by 16 in. pulley for belted application developed a galled bearing. An investigation of the bearing reaction showed the necessity of attention to the bearing metal. The bearing pressures were analyzed as follows:—

$$\textit{Belted Speed} = V = \frac{\pi\, d\, N}{12} = \frac{3.1416 \times 16 \times 1200}{12} = 5050 \textit{ ft. per min.}$$

$$\textit{Journal Speed} = V' = \frac{\pi\, d_1\, N}{12} = \frac{3.1416 \times 4 \times 1200}{12} = 1260 \textit{ ft. per min.}$$

$$\textit{Pull on Belt (Fig. 6)} = P = \frac{HP \times 33000}{V} = \frac{150 \times 3300}{5050} = 982 \textit{ lbs.}$$

Assuming the proper co-efficient of friction and 160 degree arc of contact, the total pull on the pulley shaft can be approximated as $3\,P$, hence $3\,P = 3 \times 982 = 2946$ *lbs*

The bending moment at the center of shaft, Fig. 7, is then $M_b = 3\,P_1 = 2946 \times 15 = 44200$ *inch-lbs.* The section modulus $= Z = \frac{\pi\, d^3}{32} = 6.4$. The stress in the most remote fibre of the shaft is:—

$$f_b = \frac{M_b}{Z} = \frac{44200}{6.4} = 6900 \textit{ lbs. per sq. in}$$

The rear bearing reaction is:—

$$R = \frac{2946 \times 44.5}{29.5} = 4442 \textit{ lbs.}$$

Projected area of bearing is:—

$$A = 4 \times 10 = 40 \textit{ sq. in.}$$

Pressure per sq. in. of bearing is:—

$$p = \frac{4440}{40} = 111 \textit{ lbs. per sq. in.}$$

$$pv = 111 \times 1260 = 139000$$

While this product of journal velocity times the unit bearing pressure is high, it is still within operating limits, provided proper attention is given the bearing metals. In this case the lead base babbitt was changed to a tin base and the bearing operated satisfactorily.

It frequently happens in repair shops that the babbitt is poured directly into the shell, completely filling it. The shell is then drilled out to nearly journal size, then is bored or broached to dimension. This process is a waste of material and labor and produces a decidedly inferior bearing. A better method is to introduce a small mandrel into the shell and then pour in the metal. After withdrawing the mandrel the metal is broached to size. This has the advantage over the previous case in that it saves the operation of boring, but the usefulness of the bearing has not been increased over the first method.

The proper babbitting of the bearing depends upon the temperature at which the babbitt metal is poured, and the temperature of the shell at the time of pouring. The metal temperature is most readily maintained at the proper heat by means of an electric babbitt metal pot, as shown in Fig. 8. These pots are now designed in nearly all capacities up to 750 pounds molten metal weight and are maintained at a constant temperature by means of thermostatic control. The temperature variations are very small, insuring that the babbitt will be poured at the proper temperature, which cannot be determined by any haphazard rule of thumb method. In all motor applications, a first class quality of babbitt is an excellent investment. It is poor practice to combine all of the various babbitt metals used throughout a mill into one pot producing a conglomerate mass of no definite quality. For common rough mill bearings this may be entirely satisfactory but not for motors, especially those of high speed.

The introduction of a mandrel, approximately one thirty-second inch smaller than the finished journal dimension and properly centered, followed by the pouring of the metal in a skillful and scientific manner, produces excellent operating results. The reason for this is identical with that which is obtained from

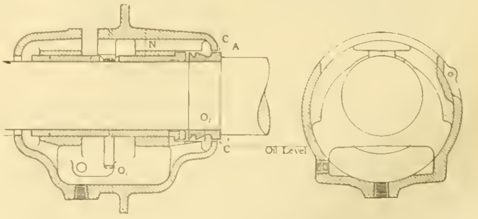


FIG. 4—PREVENTION OF OIL LEAKAGE

The communicating chamber *N* performs to some extent the function of pipe *L* in Fig. 3, for if chamber *N* did not exist and the oil level in the bearing housing was raised to the point indicated, there would be no air passage from chambers O_1 to chamber O_2. Then, assuming a partial vacuum at *A*, this partial vacuum will be communicated to chamber O_2. To equalize the presure acting in chamber O_1 and O_2 the atmospheric pressure acting in chamber O_1 upon the body of oil, will raise the oil level in chamber O_2 causing leakage at point *C*. With the introduction of the communicating chamber *N* the pressure equalization bettween chambers O_1 and O_2 is effected by passage of air through passage *E*. The same result would be obtained by using a pipe such as *L* in Fig. 3.

chilled casting practice. With excessive drilling and broaching the chilled portion of the babbitt metal is cut away. With a mandrel very nearly the journal

size, the excessive labor item is reduced, and the chilled portion of the babbitt is not reduced by broaching, but remains as a wearing surface. This produces a bearing which is hard but does not score under proper attention, is relatively inexpensive and has a long life. Under the most severe conditions, it may become necessary to roll the babbitt by means of a hardened steel roller, introduced within the bearing shell, the bearing shell being turned against this roller under pressure. For geared motor applications, where the service is severe, it is often advisable to resort to bronze bearing shells with a tinned bearing surface. The bearing is first turned to size and after tinning it is broached. The tin is almost entirely absorbed by the metal, filling the pores and thus forming a smooth bearing surface, hard and durable, and which will not peen out under the vibrations which are characteristic of this class of service*.

In general, it should be observed that journal speeds should not exceed practical limits, particularly where the bearing pressures run high. Ordinarily, it is considered good practice to maintain 1200 feet

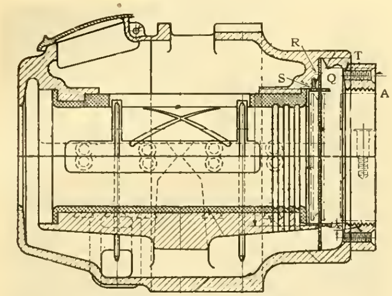


FIG. 5— AN EFFECTIVE SEAL WHERE THE DIRECTION OF ROTATION IS CONSTANT

A chamber Q is formed by oil shields *R* and *S* through which the shaft passes. Pressure in this chamber, greater than the atmospheric pressure acting in other chambers of the bearing housing, is maintained by use of collar *T*, secured to the exterior of the bearing housing. Collar *T* and the end of the bearing housing are threaded as shown, so that the end of the thread clears the shaft by a small margin. The threads are cut right hand and left hand, depending upon which end of the motor is considered and the direction of rotation, to secure the result that air, travelling around with the shaft within the threaded section, is caused by friction to follow the threads and pass axially into the interior of the housing. In this way pressure instead of partial vacuum is created in chamber *Q*, counteracting the effect of the partial vacuum at point *A*.

per minute, at bearing pressures not exceeding 150 lbs. per square inch belted load.

This leads to the consideration of belt speeds, which should not be over 5000 feet per minute; otherwise centrifugal force tends to lift the belt off the pulley, reducing the efficiency**. The following illustrates a case where a rubber belt was used with a 75 hp motor. The belt, after a short period of operation showed a defect from manufacture. On the driving side a slight opening developed, admitting air which, on passing over the pulley, was compressed along the belt for a distance of some three feet. As the air pocket approached the pulley, the belt inflated to a thickness of about four inches before it passed around the arc of contact. Upon release of the pressure the air discharged with a loud report; the bearing became hot due to excessive stress caused by the bag of trapped air. The remedy was a number of slits cut in the top ply of the belt, parallel to its length, permitting the air to escape.

In certain industries, such as textile and cement mills, the belts are pulled to a tension which approaches the breaking point, for the purpose of preventing slip. If the ordinary commercial motor is used for such duties, the shaft deflections become excessive and may cause rapid bearing wear and reduction of the air-gap, which is necessarily small for high efficiency and high power-factor alternating-current motors. In a cement mill such a condition was demanded; and to insure proper operation a 75 hp motor was redesigned with a shaft nine inches in diameter to reduce the excessive deflection which would have prevailed had a standard motor been applied.

Generally, a standard motor should be chosen for the following reasons:—

1—Design troubles have been eliminated by rigid tests and standard processes before the motor is offered for sale in the open market.

2—Prompt shipment can be made from stock, and if not, they can usually be built up quickly from standard stock parts.

3—The cost is less than for a special motor, because advantage can be taken of quantity production.

4—The user can standardize the motors installed to a large extent and thus reduce spare parts. This spare stock multiplies very rapidly as odd types of motors are installed.

5—Reducing the number of spare parts, reduces the amount of capital invested for material that may not turn over for some considerable period of time.

6—Renewal parts are more readily obtained as they can usually be supplied from factory stock.

With the large number of sizes available, a motor can usually be selected that will perform the duty required. Possibly some slight modification, such as gear ratio, will allow proper speeds to be obtained. If this is possible it facilitates standardization with the advantages enumerated above.

Cases of trouble occur where consideration has not been given to the correct mounting of the pulley or gear upon the shaft extension, frequently referred to as the "overhang" of the pulley or gear. If the pulley is mounted at an extreme distance from the center of the bearing, the stresses in the shaft are increased in direct proportion to the distance from the center of the bearing to the point of application of the load; in other words, if the distance from center of bearing to center of pulley or gear is doubled, the resulting bending stresses are doubled. The deflections produced increase, however, approximately with the cube of the distance; i. e., if the distance is doubled the deflection will be approximately eight times as great. Due at-

*For a more detailed description of babbitting methods see Westinghouse Folder No. 4474 entitled "No. 25 Alloy" by T. D. Lynch.

**See article on "The Determination of Pulley and Belt Sizes" by C. B. Mills, in the JOURNAL for Sept. 1910, p. 729.

tention should be paid to the location of the gear or pulley in order to reduce these stresses and deflections to a minimum. There is a practical limit within which this may be accomplished. The pulley or gear should be mounted to allow just enough space between it and the face of the bearing housing, to permit reaching behind it, should it become necessary to remove the pulley or gear. Where taper keys are used, space must be allowed to permit the inserting of a wedge or bar to remove the key without injuring any of the adjacent parts. Where loose and tight pulleys are required, it is obviously a gross error to mount the loose pulley between the tight pulley and the bearing housing, since the loose pulley transmits no power, hence, exerts no appreciable pull; however, upon shifting the belt to the tight pulley, the belt tension due to the load is then applied at a maximum point from the bearing center, which subjects the shaft to an excessive stress. Hence, for successful operation, the tight pulley should always be next to the bearing housing and the loose pulley outside.

Where machines are directly coupled, the center of the driven shaft should coincide with the center of the driving shaft. It is sometimes found that machines are mounted directly upon concrete foundations, and shimmed. This is not good practice, as vibrations may disintegrate the concrete and allow the machines to get out of alignment. It is best to mount coupled machines, on a cast-iron bedplate, accurately machined on both top and bottom sides. The machining of the bottom is of great assistance when mounting sets in the shop, as it facilitates assembling and prevents springing or rocking of the bedplate. The advantage of a cast-iron bedplate is further shown when the fact is considered that dowel pins should be used for securing machines after they are placed in their proper positions. Dowel pins should be located on the coupling end and at least two dowels used per machine. This will permit removal of the machines to change armatures or couplings. A cast-iron plate also permits the proper tightening of foundations bolts without danger of crushing the foundation, as may be the case with brick or concrete.

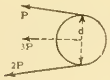


FIG. 6—PULL ON BELTS

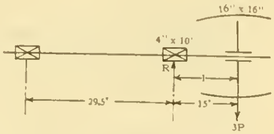


FIG. 7—BEARING PRESSURES

Couplings should have an "iron to iron fit," which means that both the coupling bore and the shaft diameter are of exactly the same dimensions. Millwrights often insert a coupling or gear in a bath of boiling water, which facilitates forcing them on the shaft. In the case of sprocket wheels, this is of particular merit since it may be necessary to repair the chain, and the wheel can be removed without difficulty. Again, it may be necessary to change the gear ratio, or replace a worn out gear; in such cases a tight fitting gear is a source of great annoyance and there are cases where it became necessary literally to cut the gear from the shaft. Motors which have solid bearings and brackets, should never have the coupling or gear too tightly mounted. A bumping fit is most satisfactory and will prove a time saver.

With high-speed pinions, poor meshing of the teeth creates considerable noise, and rapid wear. The proper key for such mounting is a feather key with clearance on the top and snugly fitting at the sides. A poorly fitted key or pinion will endanger not only the machine, but may become a hazard to workmen. Under the continued vibration to which these machines are necessarily subjected, the pinion and gear eventually may work loose, if proper fits are not maintained. Shafts are often damaged in the keyway from negligent fits, especially with motors used on reversing duty. With the advent of electric welding, it is now possible to build up the shaft.

FIG. 8—ELECTRICALLY-HEATED BABBITTING INSTALLATION
The control is mounted on the column

A convenient and satisfactory way of mounting a pinion is the use of a taper shaft end. This is more expensive, but for severe service, such as mill or railway work, it is found to be necessary. A taper fit permits easy removal of the pinion, and insures, not only a good and tight fit but a true fit as well.

Although taper fits are desirable for gears, pinions and solid couplings, they are not practical for flexible connections, on account of the space required by the nut which forces the coupling half upon the tapered end of the shaft. It is commonly thought that a flexible coupling is a cure for all misalignments, regardless of their occurrence. This is true only to a limited degree. The real purpose of resorting to a flexible coupling or connection is to absorb shocks in order to protect the motor.

To choose a solid or flexible coupling, the character of the load in each specific instance should first be considered. If the load is of the uncushioned charac-

ter such as a metal working machines, a flexible coupling should be selected. Where perfect alignment or a continuous steady load can be maintained, a solid coupling should be selected. As a general rule, solid couplings are used for connections between shafts whose bearings are mounted upon the same rigid iron

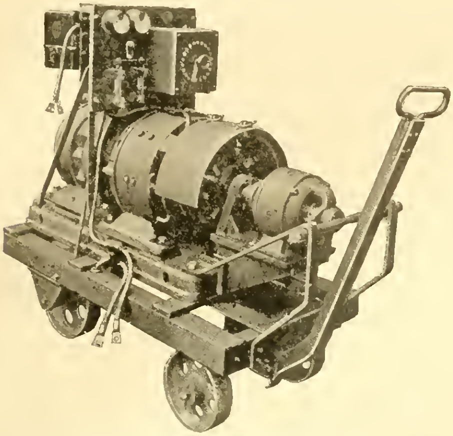


FIG. 9—PORTABLE ARC WELDING OUTFIT

In addition to building up damaged shafts, such an outfit can be used for innumerable applications in a modern shop.

foundation, bedplate or frame work. Where the machines are liable to drop out of the alignment, a flexible unit should be installed.

In the selection of flexible couplings several points should be borne in mind;—first, any part which is subjected to wear and tear, must eventually be replaced. Therefore, the coupling should be simple of design and construction, and capable of having the worn parts easily replaced. Too frequently the flexible features of couplings require special parts which must be kept in stock; if the coupling fails and these parts are not on hand, a makeshift of some kind must be devised. Second, the coupling should be symmetrical and well balanced. Third, to eliminate delays during repairs, the adjacent parts should be accessible, for in case of failure more time may be consumed in dismantling, than in the actual repair and reassembly. Fourth, the number of actual working parts should be as few as possible, as this facilitates handling and quick replacement.

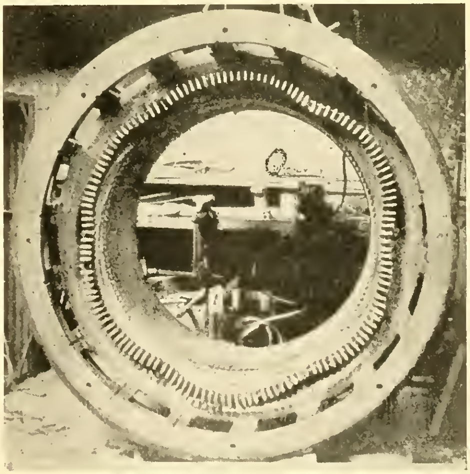
If the shaft has a solid flange forged on, by which it is coupled to the adjacent members, the shaft is sometimes turned down in order to keep the diameter of the flange as small as possible and permit insertion of the bolts for a short distance. Experience has shown that this is dangerous practice since a slight degree of misalignment, may cause a bending of the shaft, which is concentrated in the turned down section.

When there are liable to be sudden shocks, a flexible coupling should be used to protect the motor. This should be done for the same reason for which the millwright uses a "wobbler" coupling,— to protect the apparatus which is vital, and whose repair would be costly. Not only is this true in cases of shocks but, with certain loads where vibrations are carried directly to the motor and parts through the solid connections, blower vanes, rivets, even motor frames will break, due to crystallization. Rotor bars may break loose from the end rings; and leads, exposed to such vibrations may break, causing short-circuits, and serious damage to the machine. For all such classes of service the flexible coupling is a protection. Many cases of break down have been due directly to lack of this feature; subsequent installations, using a flexible coupling, have proved successful thus bearing out the importance of having a cushioned element.

Where a motor is geared, the application of a flexible coupling is not always possible, though it may sometimes be accomplished by using an intermediate shaft. Gears may cause considerably shock, when reversing under load, due to the back lash between the teeth. For this reason gears should be machine cut, and of the best of material, so as not to wear rapidly. Pinions should be made of forged steel, heat treated. Meshing gears for steel mill work should be cast steel, as it has been found that the severe service imposed upon them cause an uneven wear of cast-iron teeth.

Effect of Connecting a Generator to the Line Out of Phase

D. GOODFELLOW



This 900 kw, 25 cycle, 6 pole, 2300 volt generator delivered its rating for several months after receiving the "bump". The winding plainly shows the six points where the short-circuit stresses must have centered.

Motor Driven Plate Mills

F. D. EGAN
Steel Mill Engineer,
Westinghouse Electric & Mfg. Company

PLATE mills are divided into two general classes—sheared plate mills and universal plate mills. The original plate mills were two-high and non-reversing, passing the plate back over the top roll idle. This mill was expensive in the use of labor and wasteful in the temperature of the plates. This was followed by the two-high reversing mill which, while eliminating considerable labor and allowing the plates to be rolled thinner than was possible with the two-high non-reversing mill, yet was expensive in its operation, due to the use of the reversing steam engine. The next development in this country was the introduction of the three-high mill. This mill allowed the use of a non-reversing engine. It was as fast as the two-high reversing steam-driven mill and rolled a plate with better finish than was obtained from the two-high mill. The highest development of the three-high mill is the Lauth type, which is almost universally used in this country for rolling sheared plate.

TWO-HIGH MILL

The simplest of the two mills used in this country today for rolling sheared plate, is shown schemati-

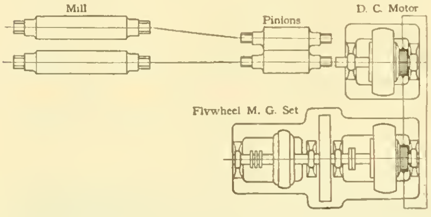


FIG. 1—TYPICAL DRIVE FOR TWO HIGH REVERSING PLATE MILL

cally in Fig. 1, consisting of two plain horizontal rolls. Both the top and bottom rolls are driven by spindles from a two high stand of pinion housings. The location of the bottom roll is fixed but the top roll is raised and lowered by an electric screw down, operating against a hydraulic cylinder at constant pressure.

The two high mills are used for producing plate when the finish is not so important and are also used for roughing mills in tandem combinations. A two high reversing plate mill is shown in Fig. 2.

THREE-HIGH MILL

A typical three-high Lauth-type plate mill is shown in Fig. 3, consisting of three plain horizontal rolls, the middle roll being smaller than the other two. The top and bottom rolls are driven in the same direction by spindles from a pinion housing, while the middle roll is alternately driven by the top and bottom roll by friction.

In the older mills, pinion housings were arranged as shown in the upper part of Fig. 3. The middle pinion was driven and was located on the same center line as the top and bottom pinions and was usually about two-thirds the pitch diameter of the main pinion. Below is shown a set of Kennedy pinion housing which allows a reduction of from 4 or 5 to 1. This pinion housing allows the use of a higher speed motor, while on the older drives the motor speed was determined entirely by the speed of the main rolls.

A 160 inch three-high Lauth-type plate mill is shown in Fig. 4 as installed at the Gary Plant of the Indiana Steel Company. This is the largest three-high plate mill that has been built. Fig. 5 shows the 7000 hp motor driving this mill*, the largest steel mill motor that has been built to date. It is a specially designed motor developing a starting and pull out torque of 30 000 hp. The flywheel is assembled in the rotor of the motor which is direct connected to the lead spindle

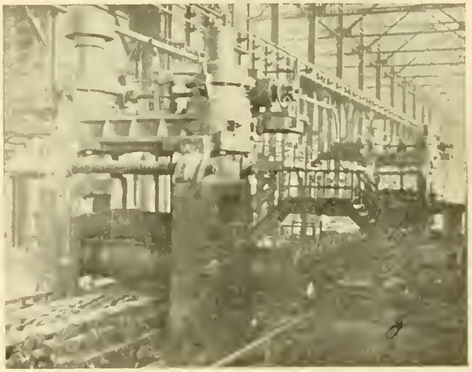


FIG. 2—84 INCH COMBINATION PLATE MILL
Entering side of roughing stand in foreground.

of the mill pinion housing. It is difficult to embody adequate flywheel effect in the rotor of a motor, but this motor is connected to a large power system, so that full equalization of the load is not essential.

Fig. 6 shows the 5000 hp motor driving the plate mill of the Brier Hill Steel Company. The motor is direct connected to a separate flywheel mounted in its own bearings and direct connected to the pinion shaft of the Kennedy pinion housing. The motor operates at 197 r.p.m. while the main rolls operate at approximately 46 r.p.m. giving a speed reduction of about 4.3 to 1.

UNIVERSAL MILL

A typical, two-high, universal plate mill is shown in Fig. 7, consisting of a set of two-high, plain cylin-

*This motor was described in the JOURNAL for June 1919, p. 254 by Mr. H. L. Barnholdt.

drical, horizontal rolls and two sets of plain cylindrical, vertical rolls, one set of vertical rolls being located on each side of the main horizontal rolls. Both sets of vertical rolls are independently adjustable by means of electrically-operated screws. The product

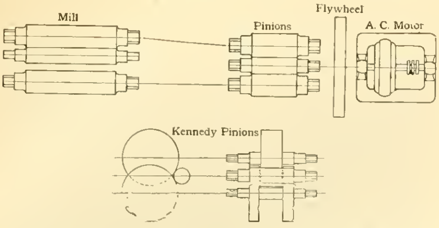


FIG. 3—TYPICAL DRIVE FOR THREE HIGH PLATE MILL

of this mill is relatively narrow when compared to plates rolled on the two or three-high mill rolling sheared plate.

The 60 inch universal plate mill at the Sparrows Point Plant of the Bethlehem Steel Company is shown in Fig. 8. This is the largest mill of this type that has been built** and is designed to roll 13 by 62 inch 10 000 lb. slabs to 3/8 inch by 60 inch plate in 21 passes. passes.

An exception to the two-high universal plate mill described above is the three-high universal plate mill at the Indiana Steel Company Gary plant. This mill is driven by a two-speed motor.

COMBINATION MILLS

In rolling very thin plate, or where the production should be increased, combination mills have been installed. These mills, with one exception, consist of two stands of three-high rolls arranged in tandem and are usually about 84 to 90 inch mills of the Lauth type.

Fig. 9 shows the arrangement of two stands of three-high rolls forming a tandem plate mill. In this arrangement, the three-high roughing mill is driven through a set of cut herringbone pinions by a slow-

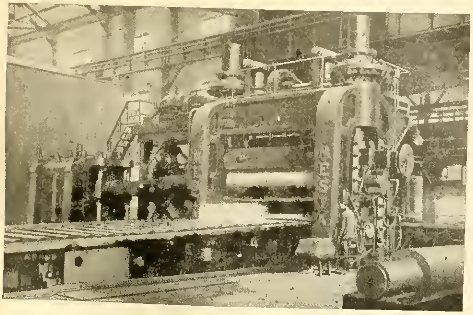


FIG. 4—160 INCH THREE HIGH LAUTH-TYPE PLATE MILL

speed motor, with a flywheel located between the motor and pinion housing. The finishing mill is driven through a standard herringbone gear unit with the flywheels located on the pinion shaft of the gear unit. The slow-speed shaft of the gear unit is coupled to the lead spindle of the cut herringbone pinions. It should of course be understood that both stands of a tandem mill can be driven by motors direct connected, as is shown for the roughing stand, or by geared motors, as is indicated for the finishing stand. In a number of instances both stands are driven as is shown for the mill on the lower half of Fig. 3.

During the development of the present three-high plate mills, the two-high reversing mill was superseded by the three-high mill, due to questions of economy and price of the reversing engine. In arranging tandem combination mills, it was natural to follow the practice of steel mills using single-stand plate mills, and to build the tandem mills with a three-high roughing and finishing stand.

The 84 inch tandem plate mill of the Brier Hill Steel Company—the exception mentioned above—uses

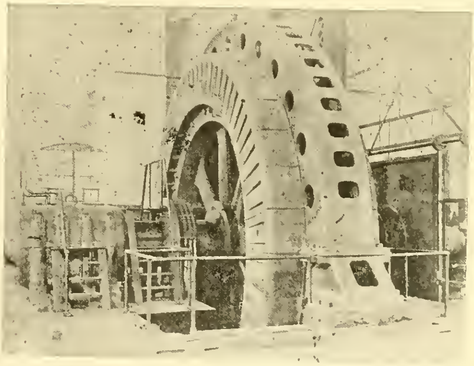


FIG 5—7000 HP INDUCTION MOTOR DRIVING THE MILL SHOWN IN FIG. 4
This is the largest mill motor yet built

a two-high roughing stand and a three-high finishing stand, both electrically driven, as shown in Fig. 10. The production of this mill proves that the motor-driven reversing roughing stand gives a much faster mill than a tandem mill with a motor-driven three-high roughing stand. The characteristics of the reversing steam engine do not provide the exactness of control necessary for operating the roughing stand fast enough to duplicate the tonnage of this mill. Due to the rapidity of operation of the roughing mill, it is possible to roll a plate to a smaller gauge than has been found possible with tandem mills using a three-high roughing stand.

An oscillogram taken on the direct-current motor driving the roughing stand of the Brier Hill 84 inch tandem plate mill is reproduced in Fig. 11. This oscillogram was taken while the mill was rolling 3 by 17 by 41 3/8 inch, 600 lb. slabs to 3/16 inch plate. Seven passes were taken in the roughing stand and the plate was then finished in the three-high stand. The mill

**A description of the equipment for driving this mill by Mr. R. B. Gerhardt was published in the JOURNAL for Sept. 1920, . 363.

was rolling one slab every 20 seconds, this time including the intervals between the slabs, as well as the intervals between passes. At this rate the mill was operating at the rate of 180 slabs an hour, while the record on this mill is 220 slabs an hour or when the ossillogram was

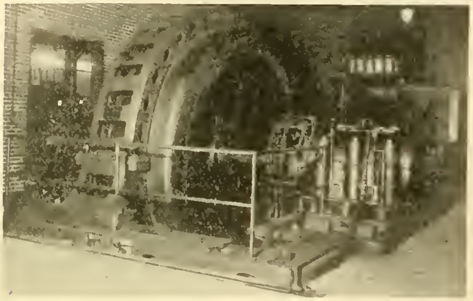


FIG. 6—5000 HP INDUCTION MOTOR DRIVING A 132 INCH THREE HIGH PLATE MILL

taken, the mill was operating only 82 percent as fast as the mill record. An inspection of Fig. 11 shows that the seven passes were made in 15.6 seconds or an average of one pass every 2.21 seconds which includes the duration of pass, the reversal and the interval between passes; pass 4 was made in 1.8 seconds. Very little difference in time was required in the duration of the different passes, due to the increase in delivery speed of the rolls to suit the individual pass. Fig. 12 shows the electrical equipment for driving this mill*, and the mill itself is shown in Fig. 2.

TYPES OF DRIVE

Present practice embraces two types of drives. First, the constant-speed, three-high mill driven by an induction motor. Second, the two-high reversing mill

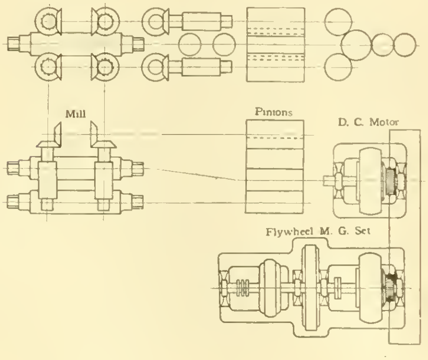


FIG. 7—TYPICAL DRIVE FOR A TWO HIGH REVERSING UNIVERSAL PLATE MILL

driven by a reversing direct-current motor having a wide range of speed. Merchant mills, structural mills and rail mills call for an alternating-current adjustable-speed drive, although such a drive has never been used in this country for driving plate mills. In England a direct-current motor and flywheel motor-generator set are being installed for driving a three-high plate mill, the speed of the motor being adjustable over a wide range.

*A complete description of this equipment was published in an article by G. H. Haney in the JOURNAL for May 1919, p. 188.

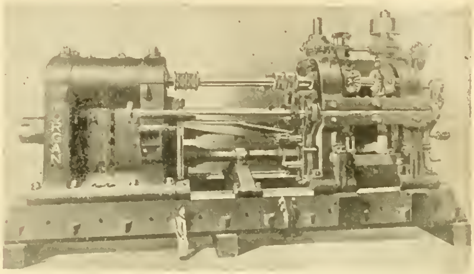


FIG. 8—60 INCH UNIVERSAL PLATE MILL
This is the largest mill of this type yet built

There are three general methods of driving three-high Lauth mills:—

1—Direct-connect the motor to the flywheel shaft by means of a flexible coupling and connect the flywheel shaft to the lead spindle by means of a mill coupling, as shown in Fig. 3. The flywheel bearing next to the mill should be equipped with a thrust bearing.

2—Direct-connect the motor by means of a flexible coupling to the high-speed shaft of the herringbone gear unit with the flywheel located between the slow-speed shaft of the gear unit and the mill; or use two high-speed flywheels on the pinion shaft of the gear unit, and direct-connect the slow-speed shaft to the mill. Both of these methods are shown in Fig. 9.

3—Direct-connect the motor to the flywheel shaft by means of a flexible coupling, and connect the flywheel shaft to the pinion shaft of a Kennedy pinion housing, as shown in Fig. 10.

The cost of a motor for such drives will decrease and the electrical performance will be improved with an increase in speed. In order to compare the slow-speed drive with a high speed unit, the cost of the gears

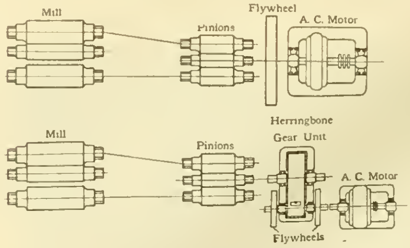


FIG. 9—TYPICAL DRIVE FOR A THREE HIGH COMBINATION TANDEM PLATE MILL

must be included with the cost of the high-speed motor. If it is necessary to give consideration to power-factor correction, the cost of the necessary corrective apparatus must be included with the slow-speed motor, this equipment being of sufficient capacity to give the same power-factor as the high-speed motor. The cost of the flywheels, necessary bearings and couplings will likewise have to be compared before a final decision

can be made as to the equipment that should be installed.

CONTROL

The control for a constant-speed motor drive is shown in Fig. 13. It consists of a forward and reverse oil circuit breaker and a liquid slip regulator for the secondary control. There are three methods of controlling the secondary of a wound motor induction motor. The first is to have a permanent amount of slip resistance in its secondary circuit; the second uses notch-in relays in conjunction with the secondary resistance and the third is by liquid slip regulator.

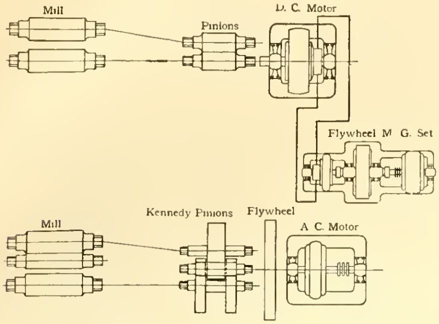


FIG. 10—TYPICAL DRIVE FOR A COMBINATION TANDEM PLATE MILL WITH TWO HIGH REVERSING ROUGHING STAND AND A THREE HIGH FINISHING STAND

With a permanent slip resistance in the secondary of an induction motor, its speed drops off in direct proportion to the load. This scheme does not utilize the flywheel to its best advantage, as the flywheel should not be called upon to give up energy until the motor has first been fully loaded.

A modification of control employing fixed resistance is obtained by the addition of notch-in relays. With this type of control a permanent amount of resistance, say five percent, is placed in the secondary. When the motor reaches its full load, additional resistance is inserted in the rotor circuit, causing the flywheel to carry a greater proportion of the peak load. This type of control is too slow in inserting the additional resistance to allow the flywheel to absorb the peak. In addition the frequent closing of the heavy contactors resulted in so much trouble that the notch-in relays were usually disconnected and the drive operated with fixed permanent resistance, or the entire secondary control was replaced by a liquid slip regulator.

The use of the liquid slip regulator in the secondary is an improvement over the preceding schemes, as it more nearly approaches the ideal condition of conserving the flywheel effect until the motor is fully loaded. At the end of the pass, the load on the motor is sustained until the flywheel has been returned to its normal light-load speed*.

From the performance of the liquid type regulator it is apparent that it is best suited for plate mill applications and can, therefore, be selected regardless of whether the motor and flywheel be directly connected or geared.

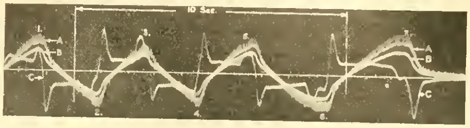


FIG. 11—OSCILLOGRAM OF MOTOR DRIVING THE ROUGHING STAND OF THE MILL SHOWN IN FIG. 2

A—Speed curve. B—Voltage curve. C—Current curve Numbers 1 to 7 indicate the various passes. The time is indicated in seconds along the zero line.

REVERSING DRIVE

The electrical equipment for driving a reversing mill is more expensive than is required for driving the three-high mill, yet the total costs of the mill and drive installed are about the same for the two types. The production of the tandem mill using a two-high roughing stand is much higher than that of a tandem mill with a three-high roughing stand. At the Brier Hill Steel Company's plant there are more delays on the three-high finishing stand than on the two-high roughing stand. Fig. 14 shows a schematic diagram of a double unit reversing motor drive. The motor is rigidly coupled to the lead spindle of the pinion housing by means of a universal coupling. The power

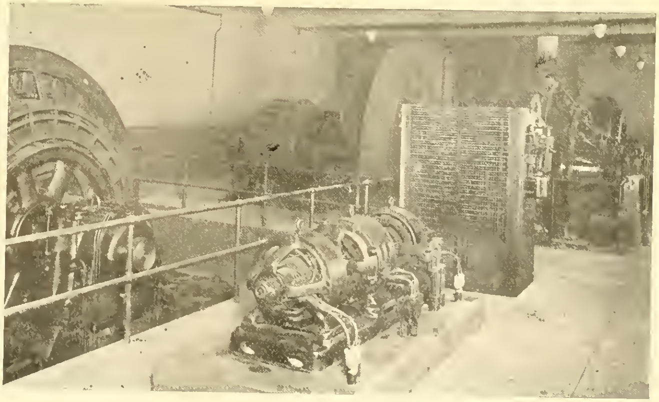


FIG. 12—REVERSING EQUIPMENT FOR DRIVING THE ROUGHING STAND OF THE 84 INCH COMBINATION MILL SHOWN IN FIG. 2

*The characteristics of a motor operating with fixed secondary resistance, with notch-in relays, and with the liquid type regulator are discussed in detail, with motor speed-torque curves and graphic meter records in an article on "Electrical-Driven Plate Mills" by G. E. Stoltz in the JOURNAL for Feb. 1919, p. 69.

supply for the reversing motor is supplied by a flywheel motor-generator set. This set consists of two direct-current shunt wound generators and an alternating-current wound rotor induction motor, rigidly coupled to the shaft of a flywheel mounted in water-cooled bearings and located between the motor and one of the generators. The direct-current system is generally 600 or 700 volts per machine, while the driving motor is designed to suit the main alternating-current supply circuit and is usually either 2200 or 6600 volts, 25 or 60 cycles. The exciter set consists of an induction motor driving a constant potential and a variable potential generator. The variable potential generator has its field circuit in series with the main direct-current armature circuit and its potential varies with the motor current, supplying a field to the main mill motor that is proportional to the main motor armature current. The constant potential generator is a standard exciter and supplies excitation for the generator shunt fields and the constant potential field of the main mill motor.

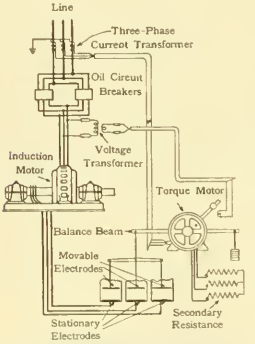


FIG. 13—DIAGRAM OF CONNECTIONS FOR A WOUND ROTOR MILL MOTOR AND LIQUID SLIP REGULATOR

Control—The control for a reversing mill drive is also shown in Fig. 14 and consists of a main switchboard panel, a forward and reverse primary circuit breaker, a liquid slip regulator for the control of the motor driving the flywheel motor generator set, a direct-current tie panel between the main mill motor and generator and an auxiliary control panel and starter for the exciter set and the blower motor.

The reversing motor is controlled automatically by magnetic switches. Adjustable relays control the rate of acceleration and retardation of the motor, so that it operates at a rate consistent with the reductions which will be taken in the mill. The control is so interlocked that the motor always has full field when starting. Further increase in speed up to the maximum occurs after the generator field has obtained full strength.

PERFORMANCE

Electrically-driven plate mills have been in operation in this country since 1907. The motor on the 36 inch universal plate mill of the Illinois Steel Company—the first reversing mill drive installed in this country—has demonstrated the reliability of electric drive, as it has been in constant operation since May 1907. In its thirteenth year of operation no delays were charged against the electric drive, yet that year the mill rolled the maximum tonnage in its history, which was 20 percent greater than that rolled during any of the first ten years of its operation.**

The reversing equipment on the two-high roughing stand of the 84 inch tandem plate mill of the Brier

SCHEMATIC DIAGRAM

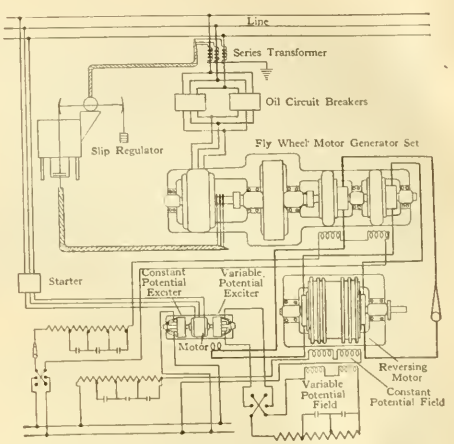


FIG. 14—DIAGRAM OF CONNECTIONS OF DOUBLE UNIT REVERSING MILL EQUIPMENT

Hill Steel Company operated its first year without any delay being charged against it. This mill holds records for the number of slabs rolled per hour, per day and per month, as well as the thinness of gauge for the width of plate rolled, as given in Fig. 15. The ability of this mill to roll the maximum number of slabs and thinness of gauge is due to the dispatch with which the

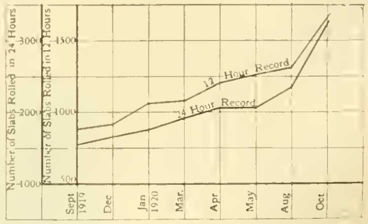


FIG. 15—ROLLING RECORDS OF THE 84 INCH TANDEM PLATE MILL OF THE BRIER HILL STEEL COMPANY

	12 Hours	24 Hours
Number of slabs	1659	3270
Number of passes in roughing mill	7	
Total charged weight-tons	373	716
Total finished weight-tons	315	518
Max. Number of slabs for one hour	220	
Finished tons of 10, 11, 12, and 14 gauge U. S. standard	23	71
Finished tons of 8 and 9 gauge	13	435
Finished tons of $\frac{3}{16}$ inch No. 10 gauge	26	6
Finished tons of $\frac{1}{4}$ inch and heavier	253	6

The large tonnage rolled and the small gauge that can be finished demonstrate the dispatch with which the steel is handled and finished before it looses its heat.

slab can be roughed down and rolled to width on the reversing roughing mill before delivery to the three-high finishing mill.

**The operating record of this motor is given in an article in this issue by Mr. W. S. Hall on p. 400.

The power consumption in kilowatt-hours per ton of plate charged weight for 132 and 110 inch three-high plate mills is shown in Fig. 16 and that of a 90 inch and an 84 inch three-high tandem plate mill is shown in Fig. 17. The power consumption of the auxiliaries of the 110 inch mill are also shown, but the other curves include the power consumed by the mill only.

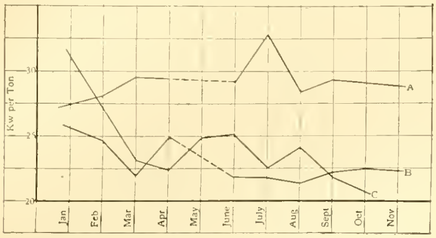


FIG. 16—POWER REQUIRED FOR DRIVING PLATE MILLS

A—Main drive of 132 inch three high plate mill; average kw per ton = 29.2.

B—Auxiliaries for 132 inch three high plate mill; average kw per ton = 22.8.

C—Main drive for 110 inch three high plate mill; average kw per ton = 22.2.

The dotted line indicates that the mill was not in operation.

The efficiency of the earliest motors driving steel mills, is as high today as at the time of their installation. This constant efficiency, which is high even at light loads, makes the electric drive highly desirable, particularly in periods of business depression, and results in a lower obsolescence charge than is the case for any steam drive. The electric motor also gives a maximum and uniform turning moment in any position, insuring ease and smoothness of starting. This, as well as absence of reciprocating parts, results in less wear and breakage in the driving units as well as in the mill parts.

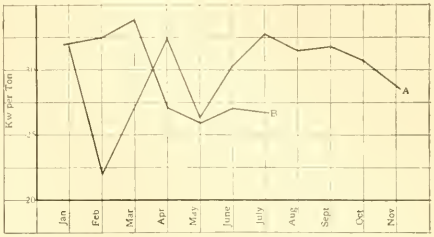


FIG. 17—POWER REQUIRED FOR DRIVING PLATE MILLS

A—90 inch three high plate mill; average kw per ton = 29.6.

B—84 inch three high tandem plate mill; average kw per ton = 28.8.

It is an accepted fact that an electrically-driven mill produces a higher tonnage than the same mill when steam driven. This is due to the fact that an electric motor maintains a higher average speed throughout the rolling cycle and to its ability to absorb energy from and restore it to the flywheel rapidly. Production is further increased by the reduction in number and length of mill delays.

Power-Factor Correction in Steel Mills

HOLLIS K. SELS
General Engineering Dept.
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THE NEED of power-factor correction is evidenced in practically every steel mill. The general characteristics of the various loads in a steel mill tend to produce a low lagging power-factor. The general characteristics of industrial loads have led central stations to discriminate between the loads of their customers, especially with reference to power-factor; or if the power is generated locally, low power-factor increases the cost of generating and transforming equipment to an appreciable extent. Low power-factors have a much greater effect on the voltage regulation than high power-factors, due to the predominant effect of the reactive drop, which may have a detrimental effect upon the performance of the connected load. And, although a point of lesser importance to the steel mill customer, high power-factor increases the system efficiency from generators to load.

The balance of power in a particular steel mill is largely dependent upon the steel processes involved, but can be controlled to some extent by the application engineer in the layout of the plant. An analysis of a well balanced plant which is completely electrified will bring out the principal items of the balance of power and the relative amounts of each as shown in Table I and shown graphically by Fig. 1, omitting the furnaces, which indicates that the average total power-factor may range from 85 to 95 percent for such a plant. As the relative amounts of power vary for particular installations, the power-factor may be correspondingly higher or lower. The present day tendency has been to improve the power-factor, but, in general, the characteristics of most installations have been such as to give poorer power-factor than necessary, whether from poor layout, poor load factor, or simply from not applying the necessary corrective factors.

Since the cost of generators, transformers, distribution lines, and transmission losses and the regulation is determined by the kv-a rating rather than the kw rating, it is to the interest of both the consumer and the central station to maintain as high a power-factor as will prove economical. On this account the central stations, in their contracts with large power consumers, have in recent years included clauses to the effect that the power-factor must be maintained

above a certain amount, depending upon the amount of total connected load or maximum demand. For other power-factors the customer is penalized or given a premium for falling below or above this set amount. Probably the most popular rate is that operating on the maximum demand rate in the direct ratio of the average power-factor of the load to the power-factor set by the central station. However, some companies do not adopt such a sliding scale, but fix definite limits of power-factor for penalizing or paying premium. In either case the tendency for the central station is to make the rates attractive enough so that the consumer will see to his own corrective apparatus.

The question of high power-factor is of nearly equal importance when the power is generated locally. If the full load power-factor is high, the kv-a rating of the generating and transforming equipment is materially reduced, thereby reducing its cost proportionately. At light loads the cost of keeping units on the line unloaded, except for reactive load, is high and higher power-factors will materially reduce these stand-by losses.

TABLE I—BALANCE OF POWER

Application	Percent of Total Load: Consumed	Percent of Total Load: Connected	Avg. P—F.
I—Electric furnaces	Special	Special	95
II—Direct-current supply a—Synchronous converters b—Motor-generator sets, which are synchronous above 300 kilowatts	30	15	100 80 lead
III—Auxiliary Drive, which may be either synchronous or induction motor	16	47	100 or 80-85
IV—Main roll induction motor drive	50	33.5	75
V—Alternating-current lighting	4	4.5	98

On account of the magnitude of the reactive drop, a small reactive component of the load will produce as much voltage drop as will the power component of the load through the resistance drop. For this reason high power-factor is important from a regulation standpoint. The effects of poor regulation in a distribution system may be two fold. First, in the performance of the connected apparatus, in that standard motor equipment is not guaranteed for more than ten percent above or below normal voltage and for a constant current, the horse-power output varies nearly as the square of the impressed voltage. The torque is also reduced as the square of the voltage. Where alternating current is used for lighting purposes the quality of the illumination is greatly affected, due to the sensitivity of the lamps to slight voltage variations. Second, the transmission losses will also be higher for poorer regulation, and transformers will usually be operated at much higher induction if they are being operated on undervoltage taps to improve the regulation at full load, resulting in higher stand-by losses as well as aggravating the poor power-factor at light loads. Transmission losses are also determined by the total kv-a load and, for a given amount of power, will be considerably higher for low power-factors.

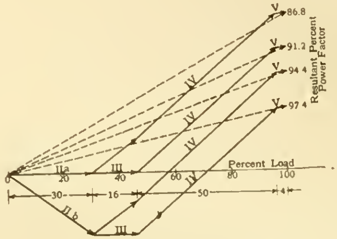

FIG. 1—VECTOR DIAGRAM

Showing possible resultant power-factors with loads of different power-factor, corresponding to the balance of power shown in Table I.

The extent to which power-factor can be economically improved should be based on an extensive system study. Although many factors effect this phase of the problem it is possible to generalize to some extent. For this purpose two particular points will be considered; first, assuming that there are no limitations in the prime mover, the amount of increased generator capacity which will be obtained on a constant kv-a basis corresponding to the added kv-a corrective factor, and second, on a constant load basis, the reduced cost in generator and transformer equipment and the reduction in losses due to increased power-factor.

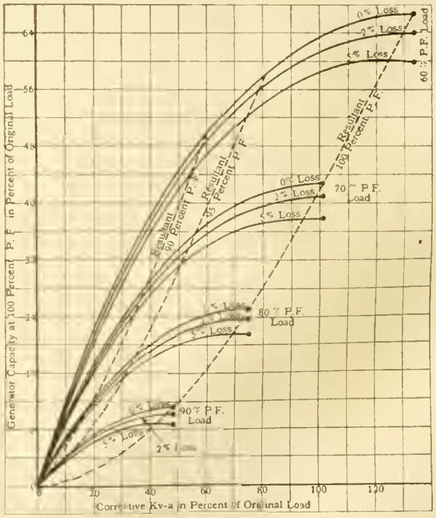

FIG. 2—EFFECT OF POWER-FACTOR CORRECTION ON ADDITIONAL GENERATOR CAPACITY AND RESULTANT POWER-FACTOR

With a constant kv—a load of 100 percent.

The curves Fig. 2, show the relation between the additional generator capacity available, corresponding

to the added leading kv-a, expressed in percent of the original load on the basis of 100 percent kv-a, and taking into account the losses in the corrective apparatus. The curves illustrate very clearly the large amount of corrective factor required in comparison to the additional generator capacity obtained in improv-

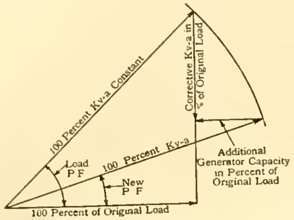

FIG. 3—DIAGRAM SHOWING HOW PERCENT ADDITIONAL GENERATING CAPACITY IS OBTAINED WITH ADDED CORRECTIVE KV-A

All in percent of original load with constant kv-a.

ing the power-factor at the higher power-factors. For example, to increase the power-factor from 90 to 95 percent requires approximately 2.5 times as much corrective kv-a as there will be increase in generator capacity. Fig. 3 shows how the curves in Fig. 2 were derived. All vector relations have been expressed in percent of the original kw with the exception of the total kv-a which has been referred to as 100 percent kv-a maintained constant. The losses of the corrective equipment are taken into account by subtracting them from the additional generator capacity available for

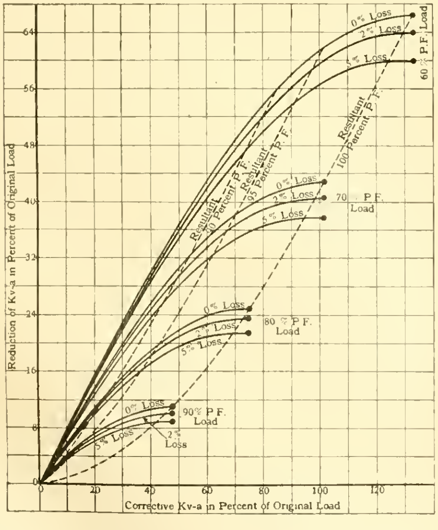

FIG. 4—EFFECT OF POWER-FACTOR CORRECTION ON REDUCTION IN KV-A AND RESULTANT POWER-FACTOR

With a constant load of 100 percent kw.

zero loss and expressing the remainder in percent of the original load.

With turbogenerator units costing approximately three times as much as synchronous condensers per kv-a installed, it would appear that it would be economical to correct to about 95 percent power-factor. However, since the turbogenerator units are usually rated at 80 to 90 percent power-factor, the power-factor could not be corrected above these values without exceeding the capacity of the turbines, if the additional generator capacity was used. By this same comparison, other means of improving power-factor can be evaluated against the cost of turbogenerator units and auxiliaries, and the economical point on the curves determined where the ratio of the additional generator capacity to the capacity of the corrective apparatus is equal to the inverse ratio of their respective costs. This point will never reach unity power-factor as the ratio at this point is zero making the required ratio of costs infinite. It must be remembered that the improvement in power-factor will mean other attendent benefits in improved regulation and decreased losses with constant kv-a which, if evaluated, may make it desirable to improve the power-factor further. The curves also indicate very clearly the effects of the loss in the corrective apparatus in reducing the increased generator capacity when neglecting the decreased

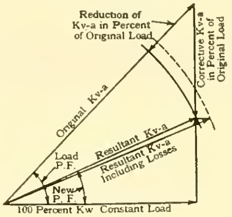

FIG. 5—DIAGRAM SHOWING HOW PERCENT REDUCTION OF ORIGINAL KV-A IS OBTAINED WITH ADDED CORRECTIVE KV-A

All in percent of original load, which is constant except for the additional losses.

losses in the remainder of the system, and show that there will be an actual loss when correcting to nearly unity power-factor. However, on account of the reduced losses in the rest of the system, the zero loss curves in Fig. 2 may be the most correct.

On a constant kw basis, improved power-factor will reduce the kv-a with a consequent reduction in the losses and an improvement in the regulation. The reduction in kv-a will give a direct saving in the transformer capacity required and the higher power-factor will permit the application of a cheaper generator. However, since the kv-a is inversely proportional to the power-factor for a given load, there will not be such a marked saving above 90 or 95 percent power-factor as there will be at 60 or 70 percent, so that correction above these values is probably not justified for a saving in kv-a rating alone. Curves similar to those in Fig. 2 are given in Fig. 4 which illustrate this point. The diagram in Fig. 5 shows how the curves in Fig. 4 were derived. All vector relations have been expressed in percent of the original load, which has been referred to as 100 percent kw maintained constant.

The losses of the corrective equipment are taken into account by adding them to the load and increasing the resultant kv-a correspondingly, which decreases the net reduction in kv-a. However, since the losses in an extensive system may be reduced sufficiently to overbalance any additional losses, the zero loss curves in Fig. 4 may be the most correct.

On the basis of either constant kv-a or constant kw the capitalization of losses should be taken into account in determining the economical power-factor. In this connection there are two factors to take into consideration; on the one hand there are the additional losses of the corrective apparatus, while on the other there is the reduction in the generation and transmission losses which tend to balance out at low power-factors but at high power-factors do not. If the power is generated locally, this capitalization in connection with the cost of the corrective apparatus and the evaluation of the additional generator capacity available or the reduction in the generator and transformer equipment will complete the study for the economical power-factor. When the power is purchased from a central station, this capitalization in connection with the cost of the corrective equipment must be balanced against the reduction in rates capitalized in a similar way.

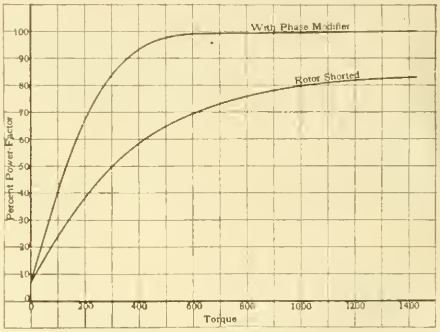

FIG. 7—IMPROVEMENT OF POWER-FACTOR OBTAINABLE WITH A PHASE MODIFIER

The first and most obvious method to be considered for the improvement of power-factor is in the application of synchronous motors in the layout of the plant, and the careful application of induction motors so that the load factor will be good and the power-factor correspondingly better. The charts, Fig. 6, show to what extent this means has been carried out in one plant. It will be seen that the power-factor on the power house is unusually high, although the other charts of the principal motor installations at this plant show the typical power-factor conditions existing in the various applications. The evident solution here is in the application of a synchronous motor-generator set operating a leading power-factor.

In addition to the application of synchronous motors to motor-generator sets for aiding in power-factor correction, Table I shows that there are numerous auxiliaries about a large steel mill that may be driven by

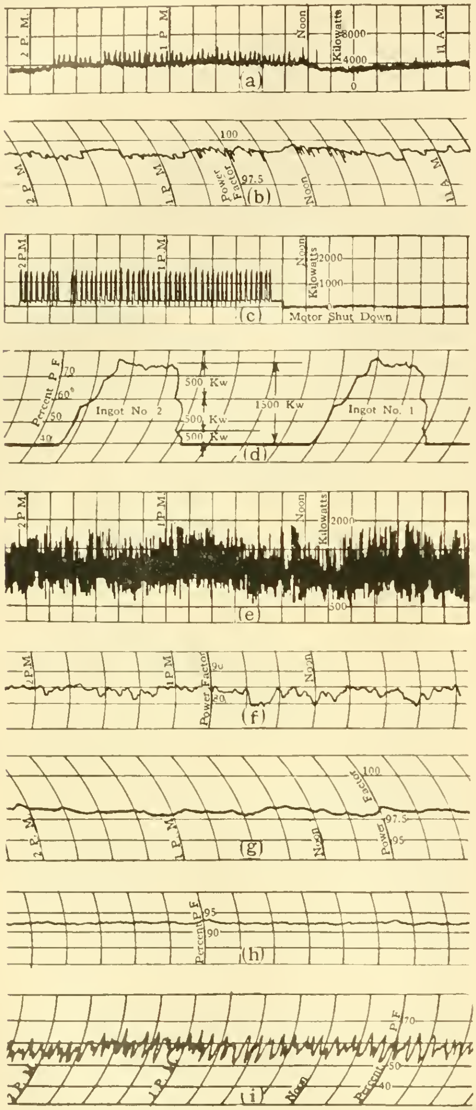

FIG. 6—TYPICAL POWER-FACTOR AND LOAD CHARTS IN A STEEL PLANT HAVING UNUSUALLY GOOD CHARACTERISTICS

a—Kw chart of day load at power house.

b—Power-factor chart corresponding to *a*.

c—Kw chart of 5000 horse-power continuous bar mill motor.

d—Power-factor chart corresponding to *c*.

e—Kw chart of 1600 hp sheet mill motor.

f—Power-factor chart corresponding to *e*.

g—Power-factor chart of 1500 kw motor-generator set at power house with leading power-factor.

h—Power-factor chart of two 500 hp river pump motors.

i—Power-factor chart of 300 hp cold roll motor.

synchronous motors. A synchronous motor may be readily designed at comparatively little additional cost to carry the same reactive kv-a as it will kw load. By the application of a constant current regulator, synchronous motors can be arranged to carry their maximum continuous rating at all times, so that at light mechanical loads they will be taking practically their full capacity at leading power-factor. This feature

TABLE II— A COMPARISON OF SYNCHRONOUS AND INDUCTION MOTORS

Synchronous Motors	Induction Motors
Auxiliary Apparatus Required	
Autotransformers	Autotransformers
D-C excitation	No excitation required
Field rheostats	No rheostat required except with wound rotor motors
Instruments indicating adjustment of field current	No instruments required
Starting friction clutch in some cases	No clutch required
Construction	
Stator	Stator
Rotating field structure with definite poles	Squirrel-cage winding or wound rotor
Collector rings and brushes	No brushes except on wound rotor motors
Starting	
Starting operations— Short-circuit field Close starting switch Apply excitation Change from starting to running position	Starting operations— Close starting switch Change from starting to running position
On some basis starting torque is usually somewhat less than induction motors with pull in torque about 50 percent of full load	Full-load starting torque on squirrel-cage and twice full load on wound rotor motors
Self starting	Self starting
Running	
Constant speed with fixed relation to generator	Constant or variable speed with elastic relation to generator
Maximum torque at synchronous speed	Maximum torque usually greater than synchronous motor but at reduced speed
Subject to hunting	No tendency to hunt
Power-factor can be controlled with excitation within design of machine and when set at full load for unity or leading power-factor, leading current increased as load decreases	No control over power-factor, which is always lagging and low for light loads and slow speed motors
On short-circuit acts as a generator	No generator action on short-circuit except during transient state
More sensitive to abnormal conditions than induction motor	Less liable to trouble under abnormal conditions

would only prove economical on the larger installations, such as a large motor-generator set. The inherent characteristics of a synchronous motor make it suitable for driving fans, pumps, compressors and other constant speed loads. A comparison of synchronous and induction motors is summarized in Table II.

Since the balance of power in some particular installations would not permit suitable application of synchronous motors which would take care of the power-factor correction, it may be necessary to employ other means of doing this. Also the layout of the plant may be such that the balance of power giving a suitable power-factor on the generator would not benefit the distribution system to the same extent. The ideal conditions for power-factor correction in order to obtain the maximum benefits would be to correct each individual load to unity power-factor. However, while possible, this would be very expensive in a large plant and totally unwarranted, in that it would require all loads either to have unity power-factor characteristics or be corrected to unity by phase-modifiers on induction motors, static condensers, or small synchronous condensers.

The use of the phase modifier has not been advanced in this country to the same extent as in Europe, where they have been used for some time. This has probably been due to the lack of attention to power-factor correction and the fact that the system is only applicable to wound-rotor motors with slight modifications in the control. However, it appears that the scheme has certain advantages, since the auxiliary machine is small and the useful capacity of the main motor is materially increased. For example, to raise the power-factor of a 1000 kv-a motor, having a three percent slip, from 85 to 100 percent power-factor will require a phase-modifier having a capacity of approximately 16 kv-a, for which a three-fourths horse-power motor would supply the losses. This will give an increase in the main motor capacity of over 17 percent, against which the increased cost of the motor due to the rotor winding and the cost of the modifier would have to be charged. The curves in Fig. 7 give a comparison of the power-factor of a motor with and without a phase modifier. By running the phase modifier at a higher speed the power factor can be made leading. This fact would be useful in the application of a single large motor in a small isolated plant to correct for the power-factors of a number of small motors.

While the phase modifier is no doubt competitive with static condensers, it is doubtful whether either method can be justified except in relatively small isolated cases. In small capacities the static condenser represents a low initial investment, is very efficient and simple in operation, but has the disadvantage of a fixed corrective capacity at only leading power-factor and of requiring a great deal of floor space. Also the characteristics of a static condenser are such as to aggravate the disturbances due to high frequency voltages impressed on the condenser and for the same reason will produce a certain amount of surging in the line when switched on and off. This subjects other equipment to unnecessary high-frequency disturbances and additional stresses which are undesirable.

Where the reactive kv-a to be supplied is of the order of 1000 kv-a the synchronous condenser installation will become the most economical. In practically every steel mill of any size the amount of leading kv-a

required will exceed this and will, therefore, be in excess of the economical application of either static condensers or phase modifiers and, since it will be more or less concentrated at one point, can be taken care of more economically in the larger blocks by a synchronous condenser. The operation of a condenser can be made entirely automatic so as to maintain the power-factor or voltage above a predetermined minimum. With automatic control no attendant will be required and only a weekly inspection is necessary. All the contingencies that might be met with hand operation are provided for, with the result that the machine is better protected than with an attendant and at a lower overall cost. Constant voltage can also be maintained at the receiver by the use of a voltage regulator.

Since the power-factor question is of paramount importance to both steel mill and central station engineers, it is to their mutual interest to consider the best means of improving system conditions with higher power-factor. The former can do much through the studied application of synchronous motors throughout the plant, either to improve the conditions in his own plant or to benefit by the reduction in rates which the latter should make available, considering the mutual benefits obtained. In this, both can be aided to a great extent by the broad experience of electrical manufacturers in dealing with such problems. In conclusion it should be emphasized that the economies produced by improving power-factor to as high as 90 or 95 percent, and in particular cases, where additional correction can be obtained at slight cost or increased size of units because of correcting for very low power factors, even higher percent power-factors are well worth considering.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

SEPTEMBER 1921

The Assembly of Complete Sets of Commutator Segments

With railway motors operating under modern conditions, using slotted commutators and high-grade graphitized carbon brushes, the wear on the commutators has been greatly reduced, resulting in a marked increase in their life. This is especially noticeable with the commutating-pole motor. Commutators on some large railway motors of the commutating-pole type have operated for twelve years without requiring turning, and show practically no wear, indicating that probably they will outlive the rest of the armature. However, such a case is the exception rather than the rule, as the commutators on most railway motors will have to be replaced at least two or three times, depending upon the type and the service conditions, during the life of the armature.

FIG. 1—CHECKING THE TEMPERATURE OF THE COMMUTATOR WITH A PYROMETER BEFORE PRESSING

SELECTION OF MATERIAL FOR COMMUTATORS

Some of the more important points to be considered in the manufacture of commutators are as follows:—

1—Use a good grade of hard drawn copper.

2—The bars should be carefully straightened and all fins and burrs removed, after which they should be thoroughly cleaned.

3—Castings should be clean and free from blow holes and all defects. They should be made of such materials as to give the desired strength.

4—The castings should be accurately machined and checked with gauges to insure interchangeability and to provide a snug fit for the built up insulation.

5—The mica segments and V rings should be built up from a carefully selected grade of mica held together with the proper bond (to prevent slipping when assembled) and baked under a heavy pressure.

6—The mica parts should be carefully machined with minimum tolerances to meet the required dimensions for the correct building up of the assembled commutator.

COMMUTATOR CONSTRUCTION

The following tabulation shows the various types of construction, the detail parts and the material that enters into the make up of the commutators.

Type	Ring nut Bolted			
Construction	V bound Arch bound Drum bound			
Mica V ring	Two piece One piece			
Materials	Metal	Segments	Hard drawn copper	Plain bars Sawed bars Punched bars Finished
		Bushings	Cast iron Malleable iron Cast steel	
		Front V	Cast iron Malleable iron Cast steel	
		Ring nut — Hot rolled steel		
		Bolts — Hot rolled steel		
	Insulation	Segments	Amber mica built up White mica built up	
		Bushings	White mica built up Micarta	
		V rings — White mica built up		

METHOD OF ASSEMBLING

When a complete set of assembled segments is to be mounted on a railway armature it is worth while to pay considerable attention to a number of small details in order to

make a good tight job. The following is an outline of a method of doing this work which has given very good results. The operations are given in the order in which they should be followed.

1—Fit the front metal V ring over the metal bushing or spider. It may be necessary to do some filling to obtain the proper clearance.

2—Fit the ring nut on the bushing. It may be necessary to clean out the threads on the bushing and nut to allow the nut to be screwed up by hand.

3—With the front V ring placed over the bushing and the ring nut screwed up tight, check the clearance of the front V ring over the nut by lifting it up against the under side of the nut.

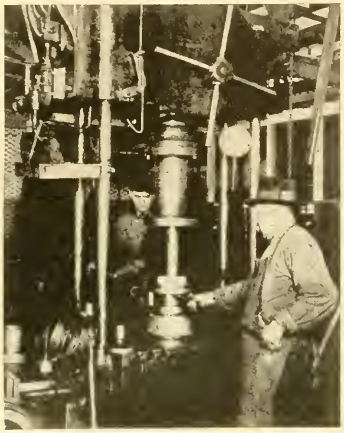

FIG. 2—FINAL TIGHTENING OF COMMUTATOR WHILE HOT AND UNDER PRESSURE

4—If it is a bolted type of commutator, the same procedure as indicated above should be followed with the bolts, etc.

5 Dismantle the metal parts and scrape off all the paint and dirt. This applies especially to the Vs.

6—Clean out the Vs in the assembled copper segments, using fine sand paper. Thoroughly blow out all dust and dirt and check for short-circuits, using 500 volts between bars. After testing, brush the inside of the Vs with a very thin coat of clean shellac.

7—Thoroughly clean the mica V rings especially at the fit of the V, using fine sand paper.

8—Assemble all parts and draw up the ring nut as tight as possible while cold.

9—Cut off the temporary band wires holding the segments together and further tighten up the ring nut.

10—Check for the alignment of the center line of commutator bar or mica (as given on commutator drawing) with respect to the center line of the keyway in the bushing.

11—Heat the commutator to a temperature of from 125 to 150 degrees C. and press while hot at from 20 to 30 tons, depending upon its size.

12—While hot and under pressure further tighten up on the ring nut, after which remove the assembled commutator from the press to cool.

13—When cold, check for short-circuits, using 500 volts beween bars.

14—Check for grounds, using a voltage of 4000 volts alternating current.

15—Press onto the armature spider or shaft and true up the face and neck.

16—After soldering, under cut the mica approximately 3-64 inch deep.

NOTE CAREFULLY THE FOLLOWING POINTS.

1—Use a good reliable make of mica insulation. Some grades look good on the surface, but are built up with an inferior bond which allows the pieces of mica to squeeze out under pressure. With this grade of built up mica it is often impossible to use these parts a second time.

2—Tighten the commutator while hot and under pressure.

3—If an oven is not available, it is preferable to heat the assembled commutator on the outside, using a gas ring, rather than on the inside.

4—In tightening the ring nut use a wrench, rather than a hammer and chisel which destroys the nut.

5—If for any reason the commutator segments have to be removed after the bands are cut, a three part clamping ring can be used to advantage to hold them together.

JOHN S. DEAN

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

2032—CHARGING STORAGE BATTERIES—I wish to install a charging outfit for automabile storage batteries, starting and lighting (6 to 12 volts). Which would you recommend, a motor-generator set or a rectifier? J. G. M. (COLO.)

Either a motor-generator set or a rectifier would be suitable for charging automobile storage batteries. The motor-generator set will probably cost two or three times as much as the rectifier with the same capacity, although it is somewhat more reliable and requires practically no upkeep or replacements. The hot cathode type of rectifier is simple in operation but it is necessary to replace the bulbs about every three months if used continuously. The power required to operate the rectifier is slightly less than required for the motor-generator set with the same charging current. With the motor-generator set it is more convenient to regulate the charging current to the battery as a hand operated rheostat is usually provided for this purpose. C. H. K.

2033—MAGNETIZING CURRENT OF INDUCTION MOTORS—Have noticed on small induction motors that by applying double rated voltage to the stator, the magnetizing current is high, due to high saturation, but as the load is applied, the current decreases. Why is this? A. M. M. (COLO.)

The phenomenon described is one which occurs very rarely in induction motors and then only when the iron is highly saturated and the impedance of the winding is high. When the magnetizing current of a motor is large and there is no load on the motor, the impedance drop is out of phase with the generated voltage. That is it does not add directly to it, but adds vectorially at an angle. When a load is put on the motor this angle will be changed and a critical point may be reached where the impedance drop, although its value may be less, is in phase with the generated voltage and will, therefore, cause it to be lower. This means a lower flux density with a lower magnetizing current. Since the current is composed mostly of the magnetizing component, the resultant current may be less even with a load component added to it. This change is usually small and occurs at very light loads. With larger loads the current will increase. L. G. T.

2034—REWINDING SMALL TRANSFORMERS—Does it usually pay to have small transformers from 5 to 7.5 kw rewound? W. L. B. (QUE.)

Assuming the current net price complete of a new equivalent transformer

as 1, the relative costs of repairs for 5 kv-a and 7.5 kv-a transformers will be somewhat as follows:—

	Repair work Done by Customer	Repair Work Done by Factory
N —New coils on with insulation	0.54	0.82
Net —New coils with insulation and new iron.	0.85	0.90

It will usually be found unsatisfactory to reassemble coils with old iron, as the impregnating compound adhering to the punchings will decrease the space factor of the reassembled iron, and cause abnormal iron losses. This trouble can be overcome if facilities are available for reannealing the iron, as this burns off the compound. It will usually be found more economical, especially with small sizes, to have necessary repairs made at service stations, or purchase new coils and iron. E. P. W.

2035—Calibrating Alternating-Current Meters—Can a potentiometer be used to calibrate alternating-current apparatus? If so how should it be used? A. A. (MEXICO)

A potentiometer can be used to calibrate alternating - current apparatus which will operate with accuracy on direct current, since the potentiometer is for use on direct current only. Voltmeters are connected in parallel with the potentiometer and sufficient voltage applied, according to the range of the instrument. If a higher voltage is required, above 1.5 volts, a volt-box should be connected between the voltmeter and the potentiometer. Ammeters are connected in series with a standard shunt, and the potential leads of the shunt connected to the potentiometer. The shunt should be of sufficient resistance to obtain approximately full scale reading on the potentiometer. Two potentiometers are required for calibration of wattmeters, and the method is the same as for ammeters and voltmeters. W. J. H

2036—Operating 22000/2300 Volt, 60 Cycle Transformer on 10000 Volts, 50 Cycles—If an old 1500 kv-a shell type transformer 22000/2300 volts, 60 cycles, is worked at 10000 volts, 50 cycles will the effective ratio increase somewhat due to the increase in flux density? In what proportion will the exciting current increase? Will the reactance and impedance be less when the transformer is worked at 50 cycles? Will the temperature also increase due to the increase in flux density? A. A. (MEXICO)

Assuming that the high voltage winding can be connected in parallel for 11000 volts, and 10000 volts, 50 cycles is impressed on this winding, the flux density will be increased in the ratio:

$$\frac{10\,000}{11\,000}\times\frac{60}{50}=1.09$$

The voltage ratio will be the same as at 60 cycles, namely,

$$\frac{10\,000}{2\,090}=\frac{11\,000}{2\,300}$$

Without knowing the particular design of this transformer it is not possible to state the inrease in exciting current, but with nine percent increased flux density at 50 cycles the exciting current is liable to be more than double of what it was at 60 cycles. For the same kv-a output the reactance will be changed in the ratio:

$$\frac{50}{60}\times\left(\frac{11\,000}{10\,000}\right)^2=1.01$$

For the same kv-a output, the temperature of the iron will increase due to the increased flux density and the temperature of the winding will increase due to the increased load currents. This increase may be partly counterbalanced by the decrease in eddy current loss. H F.

2038—Starting Current of a Squirrel-Cage Motor— A 2200 volt, 35 ampere per terminal, 150 hp, three-phase squirrel-cage motor drives a direct-current generator. The motor is started with a compensator. What starting current (approximately) may be assumed between the oil circuit breaker and the compensator and between the compensator and the motor? When the statement is made that the starting current of a motor is 2.5 times full-load current when used with a compensator, what current is referred to, the motor current or the line current? Would it conform to the Underwriter's requirements to run a smaller wire between the line and compensator and a larger wire between compensator and motor, the circuit breaker being set to protect the smaller wire and the larger wire being as many times larger as the current to the motor is larger than the current ahead of the compensator? A. L. J. (PA.)

A motor similar to this one will have approximately 300 amperes per terminal with full voltage applied at the instant of start. This current will vary in direct proportion to the voltage applied, i. e., if one-half voltage is applied to the motor, the current in the motor circuit will be 150 amperes. The current taken from the line will vary directly with the square of the voltage applied to the motor, i. e., at one-half voltage the line current will be 75 amperes. The statement "2.5 times full-load current when used with a compensator" considers the motor and compensator as a unit and means the line current. Rule 8, Page 19, of the Underwriter's rules seems to us to show that the wire between line and compensator should be large enough for 110 percent of full-load current and the wire from compensator to motor should be large enough for at least 200 percent of full-load current. C. W. K.

2039—Microlambert—The term "microlambert" is used as a measure of luminosity in connection with specifications for radium paint, such as used on clock dials and electric push buttons, etc. I would like to know the quantitative meaning of the word. For instance, if a certain paint gives six microlamberts and some time later gives three microlamberts, how am I to judge the relative luminosity? Is it a unit for measuring small quantities of light or a measure of radio activity? Is there any conversion factor to change microlamberts to lumens or foot candles. W. L. D. (PA.)

The lambert is the c. g. s. unit of brightness, the brightness of a perfectly diffusing surface radiating or reflecting one lumen per square centimeter. The millilambert or 0.001 lambert is, for most purposes, the preferable practical unit. A perfect diffusing surface emitting one lumen per square foot will have a brightness of 1.076 millilamberts. Brightness expressed in candles per square centimeters may be reduced to lamberts by multiplying by 3.1416. Brightness expressed in candles per square inch may be reduced to foot candle brightness by multiplying by $144\pi=452$. Brightness expressed in candles per sq. inch may be reduced to lamberts by multiplying by $\pi/6.45$ = 0.4868. A microlambert = $\frac{1}{1\,000\,000}$ lambert.

M. M. B.

2040—Transformer Secondary Equivalent Resistance—The test data of a 2000 kv-a self cooled 50 cycle, 67 500 Y/20 600 Y volts, 17.1/56.1 amps transformer are:— Resistance measurements at 23 degrees C. on each phase to neutral average: high tension 5.76 ohms; low tension 0.590 ohms. Impedance tests made with the high tension winding short-circuited showed the following impedance to neutral, low tension:—A=7.03 ohms, B=6.8 ohms, C=7.03 ohms, average=6.95 ohms; reactance calculated from the foregoing=6.86 ohms. Resistance calculated as low-tension equivalent= 1.137 ohms. Ratio by test using potential transformer on primary=3.19. Kindly explain how to obtain the equivalent low-tension resistance. Does the formula $R=\frac{1}{a^2}R_s$ given in Sheldon's Alternating-Current Text Book, page 164, apply in this case? A. A. (MEXICO)

The value of low tension resistance given as 0.590 ohms should probably be 0.0590 ohms. Assuming this to be correct the equivalent low-voltage resistance on one phase may be calculated from the following formula:—

$$R=R_{LT}+\left(\frac{E_{LT}}{E_{HT}}\right)^2 R_{HT}=0.0590+\left(\frac{20.600}{67.500}\right)^2\times 5.76=1.408 \text{ ohms.}$$

This is different from Sheldon's equation (p. 165) in that it gives the equivalent resistance of the whole transformer in terms of the low-tension winding, while Sheldon's equation gives the resistance of the high-tension winding only in terms of the low tension. H. F.

2041—Erosion of Steam Turbine Blades—In a reaction type steam turbine what causes the three of four rows of blading on the exhaust end to be honeycombed, cut or eroded, all other blading showing no signs of erosion. The steam is quite dirty and doubtless wet, yet the cutting is on the last rows only. An impulse turbine, under similar conditions, shows erosion on the first row of buckets where the steam strikes.

D. C. M. (WYO.)

In general this action is due to the higher blade velocity and higher steam velocity employed in the low pressure stages, together with the higher percentage of moisture contained in the steam at this point. This erosive action, is very slight when corrosive agents are absent; the latter, however, are present in varying quality and quantity in most installations.

R. E. C.

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Drive Home the Facts

P. H GADSDEN
President,
American Electric Railway Association

THE frequently predicted crash in the electric railway field, due to lawless competition and public non-support of adequate fares, has come recently in several parts of the country. Notable examples are found in Des Moines, Iowa; Bay City, Saginaw and Manistee Michigan. It is shameful that these collapses had to occur, but out of them eventually will come great good to the entire industry. The reason is that these failures will drive home through the tired feet of the former car rider and the shrinking pocket-book of the business man, the inescapable truth that electric railways are vital to the comfort and prosperity of every city in the land. The lesson will be a severe one. Even during the splendid weather which we now are enjoying, people in these street-car-less towns are rapidly coming to the bitter realization that they made a mistake in permitting their car lines to die. As weeks roll by and the weather becomes worse this lesson will be more forcibly impressed upon every car rider.

The future of the electric railway industry will be made brighter every time a hapless citizen stands in the slush on a windy corner and waits in vain for a form of transportation service which will adequately take the place of his street car. The future will be strengthened every time a merchant in a street-car-less city takes accounting of what the abandonment of street cars has meant to him in lost trade.

P. H. GADSEN, *President*
Charleston Consolidated Railway & Lighting Co.
Vice-President, United Gas Improvement Co.

It is up to every man in the industry to see that everyone, who uses street cars and is dependent upon them in whole or in part for financial success, is supplied with this same knowledge of what it means to be without electric traction service. It is unbelievable that the car riders and the business men of any progressive city in this country today would willingly place themselves in the position of the car riders and business men of Des Moines, if they knew the truth. We must make them realize that what has happened in Des Moines inevitably will happen elsewhere if electric railways are not given the proper support.

To bring this message to the attention of the general public is no easy task, but every management can and should do it. It cannot be done by writing a few letters or issuing a few statements to the press but it can be accomplished by using every available publicity channel at our command. Let your people know the truth and the truth will set you free. The facts about these street-car-less-cities are unquestioned, and when you can bring the situation home to your own people, it cannot help but impress them.

The American Electric Railway Association is anxious to help every electric railway manager to tell his people this story of service abandonment and the result on comfort and prosperity. Articles and leaflets for general distribution are being prepared and will be sent out. And the Association will do more. If you will communicate with our executive offices, it will suggest ways and means by which you can carry the story farther than it can be carried by mere printed advertising matter.

The Necessity for Publicity in Business

G. E. TRIPP
Chairman,
Westinghouse Electric & Mfg. Company

IT MUST be a matter of common knowledge that there is in process a social and political evolution in this country which is resulting in the substitution, to a constantly increasing extent, of government by public opinion for government by law.

Government by law is a characteristic of certain races, of which the Anglo-Saxon is the outstanding example, and without that characteristic our forefathers could not have established our form of government. Government by law is, therefore, a venerable institution with us and its codes and precedents are the product of many hundreds of years of experience with social actions and reactions. It has become a science so exact and important that no educational course in the curriculum of our universities is more prominent or attracts any higher order of intellect. Our judges and lawyers are men of superior ability and thoroughly trained in the practice of law; in other words, they are experts in a scientific code of rules upon which our social and business relations have in the past rested.

The departure from the straight and narrow path of government by law as distinguished from government by men is marked by the establishment of certain types of government bureaus which have more or less jurisdiction over private business but which, on the other hand, have little or no resemblance to courts of law. It is not necessary to recount the large and growing number of State and Federal Commissions and Boards in order to prove that these bureaus have multiplied rapidly in the past few years because it is well known to everyone and the development of these governmental bodies is displayed not only by increasing numbers but also by the widening scope in the essential ideas of their mission in our social and business life. It is certainly an interesting phenomenon which we are witnessing and it has some fundamental aspects which seem to demand the active attention of men of broad business experience.

The business of these bureaus is generally conducted by men who are not trained, either by education or experience, in the technique of the particular business or industry over whose destinies they preside, nor have there been, and perhaps because of the very nature of their functions, can these regulatory bodies ever build up a system of procedure, rules and precedents at all comparable with our law courts. The appointment of these business commissioners is wholly free from restrictions similar to those surrounding the appointment of our judges who must be members of the Bar and by custom have the respect and approval of their associates. Perhaps the most important distinction, however, is the uncertain tenure of office of these commissioners and the fact that political parties unfortunately are prone to regard these offices as a part of their spoils.

Certainly bureaus of this character are and must be sensitive to public opinion and here we come at once to the duty of business men to see to it that the public has full and accurate information upon which to form an opinion.

Our public utilities which have lived under regulation longer than the rest of the business world, have done a great work in publicity and the result is that public service commissions have come to be more and more judicial bodies. Of course, even in their case, there is still a necessity for keeping the public constantly informed as to business facts, and there always will be, if a sound public opinion is to be maintained, but the experience of the public utilities is a lesson to those industries which are just beginning to feel the interference with their business independence by new government bureaus or extension of old ones.

It is a question whether this growing governmental paternalism could have been avoided, or whether the pendulum will swing back, but surely there is one safe course and that is continued full and frank publicity, to the end that public opinion may be based upon economic facts instead of mere sentiment and false doctrines.

Public Utility Financing for the Future

ALLEN B. FORBES
Harris, Forbes & Company,
New York City

PUBLIC UTILITIES are public necessities to modern civilization. A modern community cannot comfortably and safely conduct its affairs without a comprehensive central system to provide transportation, telephones, light, heat and power. For maximum efficiency, the service must be both adequate and reliable and must expand to keep pace with the growth and demands of the community. First-class service from the utilities is a matter of concern and direct interest to every citizen whether he realizes that fact or not, as it directly or indirectly affects the conduct of every business and every household in the community. The demagogue may seek to confuse the issue to further selfish ends but the fact remains unchanged and unchangeable.

The war has been a great educator of the public. The public utilities have shared in the new light that has been thrown on so many matters as a result of that tremendous struggle. The problems of the railroads, the street railways, the lighting companies and the other public utilities have received a great deal of publicity. The simple economic proposition that these companies cannot continue long to give service at less than cost has been before the public eye. Politicians, demagogues, socialists and "reformers" to the contrary notwithstanding, it is a simple fact that these companies cannot continue to render their indispensable

public services unless they are allowed to charge rates that produce sufficient income to pay their labor bills, to pay their material bills and to pay reasonable "wages" in the form of interest and dividends on the money legitimately invested in the enterprise. Good service cannot be maintained in the long run unless all these bills are paid regularly. The additional capital to finance extensions necessary for the public service cannot be obtained without the definite prospect of receiving its "wages," any more than additional labor can.

No service-at-cost plan answers that does not make adequate allowance for both current and deferred maintenance or depreciation, before providing for a return on the capital invested. Otherwise, at least part of the specified return is being paid out of capital—that is, by the depletion of the property. The ideal service-at-cost plan places a premium on first-class, economical management. This has been fairly worked out in a number of cases where any decrease in rates charged the public, below a certain specified rate, entitles the company to earn and pay a contemporaneous and corresponding increase in the annual rate of return allowed on its property value.

These general considerations are obvious and must eventually be the basis upon which public utility rates are regulated. In fact, the rates of many public utilities are already being regulated on this basis. Assuming that this basis of regulation will become universal, how, in the public interest as well as the interest of the owners of the property, can the necessary capital be raised to the best advantage? The sale of mortgage bonds is apt to be the first thought, but that only partially answers the question, if in fact it answers it at all. It does not answer it at all unless, in addition to setting up a sound bond issue, a sound and conservative and workable plan for junior financing is also provided for.

Modern public utility mortages, generally speaking, provide that bonds may be issued to the extent of not exceeding 75 or 80 percent of the cash cost of permanent additions and extensions to the property. Conservative principles of finance dictate that not too large a proportion of capital requirements should be raised on borrowed money. Modern thought in the best informed banking circles is to the effect that bonded indebtedness should be kept down to an ultra-conservative figure. In the interests of bond investors, junior security holders and the public, about three-quarters of the cost or fair value of the property, whichever is the smaller, is the maximum extent to which bonds should be issuable in the case of the average public utility.

Generally speaking, bonds cannot be sold at par and it is necessary, therefore, for the company to absorb the discount at which the bonds are sold. Assuming, for example, that bonds are issuable to the extent of 75 percent of capital expenditures, and those bonds are sold by the company at 90, the company only receives about two-thirds of its requirements from the sale of its bonds, leaving the balance of one-third to be procured from other sources. How can this best be accomplished? The next best security to its mortgage bonds that the corporation can issue is an unsecured debenture or note, but if we subscribe to the sound principle above referred to, that too large a proportion of a company's capital should not be raised from borrowed money, we are forced to discard the unsecured note as a permanent method of finance even if we retain the possibility of creating it as an emergency measure.

The next best grade of security that is available is the preferred stock. In view of the fixed return thereon, preferred stock must have an investment position to be marketed successfully; that is to say, its position must be such as to give the holder reasonable assurance that he will continue to receive the fixed return specified on the face of the stock, and that, in the event of liquidation, his principal investment in the stock will be good. This in turn presupposes an equity back of the preferred stock and a suitable margin in earnings over and above the preferred stock dividend requirements. The principal way that equities are built up over preferred stock is through the medium of investment represented by the common stock and earnings on such investment. This investment may, of course, represent money already invested in the business or, in the case of new common stock issues, additional funds going in. Again, the common stock is certainly not an investment and not even an attractive speculation unless there is a reasonable probability that the investment that it represents will be allowed to earn sufficient to allow for a liberal return thereon. In other words, it is obvious that the common stockholder in taking all the speculation, therefore, is entitled to a liberal return.

It may be argued that, if a rate of return is allowed by regulatory authorities on the entire investment in the property, the speculative feature is eliminated from even the common stock, but an argument ignores the fact that a permissive rate of return is by no means a guaranteed rate of return. The Cleveland Electric Railway plan is an example of a practically guaranteed return, but there are very few such instances in this country.

To return to the broad proposition of future financing of the public utilities, the first thing to be done is to get the foundation laid for a strong structure of sound finance. That foundation is the premise that has been assumed as a background for this discussion. To establish this premise as a universal fact it will be necessary to awaken every citizen to the proposition that the public utility business is his business; to have him realize the direct interest that he has in first-class service being rendered by the utility; and to demonstrate that directly or indirectly he has

a financial interest in the utilities themselves. If he is not a utility security holder he should bear in mind that there are fifteen billion dollars of public utility securities of this country and that the banks, the insurance companies and other institutions in which he has a direct interest are among the owners of such securities. When he realizes these facts, the weight of universal public opinion should make it possible for every public utility to get fair treatment in the matter of rates, and this is the foundation upon which any permanent plan of finance must be laid. Much has already been accomplished along these lines and, combined with the educational results of the war already referred to, a great deal of light has been thrown on the problems and purposes of such enterprises.

In this connection, the plan of selling preferred stocks to the customers of the public service companies is worthy of mention. Such a program—which has been carried out successfully in a large number of cases—inures to the benefit of all concerned, giving the stockholder-customer a sound and well paying investment, making him a financial partner in the company that serves him, and giving him an insight into the problems of the company and an understanding and sympathetic point of view in connection with all its affairs. This same method should be applied in the sale of common stock, so that the public served may have the opportunity to become full partners in the business without a fixed limited return specified as in the case of preferred stocks.

With the foundation laid, the financial structure should be built or rebuilt with a sound conservative bond issue and preferred stock and common stock. In some cases perhaps the preferred stock would be omitted, but the three classes of securities are desirable to make available to the company securities to meet varying market conditions. The new series mortgage gives a degree of flexibility on the issue of mortgage obligations that has long been needed and which, to a large extent, simplifies bond financing for the future, as the prime security is always available with a duration and a face rate to meet current market conditions. The bonds will be buttressed by the preferred and common stocks. Possibly, at least the common stock should have no par value, so that arbitrary values will not be built up on the balance sheet and the stock can be sold for its market value without reference to an arbitrary par value.

The primary mistake of the past in public utility financing has been the lack of an adequate flexible and workable plan of junior or stock financing. Conditions for which the companies were not responsible, namely, their inability to charge adequate rates to permit the earning of a reasonable return on the capital invested in the business, have militated in the past against the establishment of many preferred stocks and most common stocks in a position that made them attractive and salable to investors.

The universal recognition of the equity and justice of the service-at-cost plan, which takes into account as an item of cost the wages of the money invested in the enterprise, is the first requisite in connection with public utility financing for the future. The second requisite is a conservative and well balanced capitalization. Such a capitalization, with the bonded debt limited to a conservative amount, improves the value of all the security issues of the company, removes the menace of high fixed charges, and results in a lower average cost of money to the corporation in the long run. Most important of all from the point of view of the public interest, such a capitalization, based on a rate situation where all the proper and reasonable elements of cost and value have received fair consideration, gives the maximum of facility for raising, on the best terms obtainable, the additional capital that must be provided if these great and indispensable industries are to continue to increase their facilities to meet the steady growth and demands of our communities and thus are to be able to give to the public at the lowest cost, the first-class service to which it is entitled.

The Transportation Business—A World Fundamental

M. C. BRUSH
Vice-President,
American International Corporation

THE MAN who undertakes to prognosticate in these unsettled days of readjustment and post-war conditions the outlook for the electric railway industry or any other industry is implying that he has superknowledge not properly given to anyone. One has but to look back over the period since 1914 to be thoroughly convinced that no man or group of men have been able to foretell events or conditions with any reasonable accuracy for even a few months, to say nothing of a few years. All nations, governments and industries are completely out of balance and, until a new and steady equilibrium is established, no one can guess the future. When relations between nations, between governments and between industries have settled down to a steady pace, the *relative* importance, power and necessities of nations and industries, as well as separate companies, will be different than previous to the war. In this gradual settlement to an equilibrium from the present unbalanced state of affairs, there will be a steady grinding effect, resulting in a new eventual relationship based upon the survival of the fittest, and a relative strength and importance commensurate with new international and national economic conditions. Just where the electric railway industry will fit or what the relative future of individual companies will be, is impossible to foretell. Matters both national and international are still in a chaotic condition. The world as a whole has been on a spree, and all affairs are not yet sufficiently settled and readjusted to radically changed conditions to warrant any-

one trying reliably to guess the future. This, while true of industries as a whole, is particularly true of those industries which in any way are closely allied with or dependent upon governmental supervision. Therefore, the above must be decidedly applicable to the electric railway industry. It would seem possible, therefore, at this time for us to only try to weigh conditions in a general way and to recognize certain fundamentals as they now appear to exist, while at the same moment we should apply ourselves with an intense earnestness of purpose to the administration of our properties, being prepared to study constantly and observe the kaleidoscopic and daily changes in conditions, with a willingness to modify our plans and policies consistent with such changes.

In contradistinction to the past two or three years, every man today must promptly recognize that he is an "order getter" instead of an "order taker". This applies decidedly to the electric railway industry. Railway executives must realize now, probably more than ever before, that they must actually sell transportation and they must do those things which tend to make their product attractive to their customers. There is no longer any justification for any element of mystery which has sometimes existed in regard to the management of transportation companies. The public as well as the supervisory bodies are now too vitally a party to the industry and to the management, and are altogether too well informed, for a manager to do other than recognize that facts and the truth, with a policy of absolute frankness coupled with manifest evidences of a desire to give and take a square deal, are absolutely the best policy. There is cause for satisfaction in the fact that the desperate and serious period through which public utilities have gone has resulted in a great number of instances in a full recognition on the part of the public, the press and governmental authorities of the fact that the "habit of mind", fixing the so-called five cent unit fare has been dissipated and that there is an inclination on the part of those affected by the unit fare to agree that the manufacturers of transportation should receive such payment for their "goods" as will insure their healthy existence. This makes still more important the right attitude on the part of the management toward the public and public authorities. It would appear, therefore, that there is a fertile field for electric railway executives to undertake the arrangement of such a reciprocal relationship between the man who sells his services for managerial and operating purposes, from the chief executive down, and the man who buys transportation, as will insure a fair deal and a fair return to each. The question of a fair return to the man who sells his money for such purposes, is one on which much difference of opinion exists particularly in these days when the earning power of money seems so dependent upon the reliability of the continuity of return. Fair return on capital is that rate which, with a due regard for the safety of the investment, the average man is willing to accept for the use of his money whether it be a hundred dollars or one hundred thousand dollars and is necessarily a matter of "money competition". The return which the public utilities must pay is that which will invite new capital, and this rate will in a large measure be regulated by the confidence the investor feels that the industry is to receive fair treatment from the public and governmental authorities as well as efficient, economical and intelligent administration.

The decentralization of industry which is growing since the intense war production period and is resulting in a substantial exodus from thickly settled districts to rural territory should tend to improve the field for suburban and interurban lines. This, coupled with the gradual recognition on the part of steam railroad executives that comparatively short hauls are economically the province of electric lines, should make the urban and interurban manager alert to grasp the business offered even to the extent of endeavoring to create new movements of travel. No one elment will be more conducive to successful salesmanship of such service than "Continuity of Service". The average rider is not so critical of infrequent service as he is to be promised definite service, and then find such irregularity in actual operation as to make it impossible for him to rely upon the service. Continuity of service can be secured solely through excellent management accompanied by the keenest co-operation between all of the elements which go to make up the operation of an electric railway.

Not the least important of the elements thus necessary, is the greatest care in the purchase and maintenance of equipment for, of all the injurious things tending to defeat every effort towards cordial public relationship, there is nothing which will cause more criticism than poor equipment poorly maintained, which results in exasperating delays thereby defeating the passengers' ability to anticipate departure or arrival. Elaboration on this element of transportation is justified in view of its being one of the several extremely important elements of quality of service so decidedly necessary in successful salesmanship of transportation to customers. In the last analysis, therefore, the future of the electric railway industry is very largely dependent upon the capacity and inclinations of electric railway executives.

The big capable executive will recognize that one of the great fundamentals of the world's business is transportation. He will not be bound by past practices but will be open to suggestions and criticisms, and ready and desirous of studying and accepting modified and radical changes in conditions, and ready with a thorough knowledge of his business to adapt his industry and his service to changing conditions. There is no reason why he cannot render a necessary service at all times. He must further adopt the policy of frankness with the sincere determination to give and insist upon receiving a square deal, and by so doing he will go a long way towards receiving for the service his

industry renders a fair return. The whole proposition, therefore, resolves itself into good salesmanship and, in order to sell successfully to his customers and the supervisory authorities this sincerity of purpose, he must so conduct himself as to compel absolutely confidence in his word, his judgment and his sincerity.

The Problems of the Street Railways

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Past President, American Electric Railway Association

THE history of the development of land transportation in this country is most astounding. It reveals a series of successes with few failures and demonstrates the great value to industry and society of a system which rewards individual ingenuity and effort. At all periods bold men have had visions of the necessities of the future and have built on broad and economic lines. The post rider gave way to the stage coach, which rapidly developed new arteries of travel; the coach was displaced by the Dewitt Clintons, which developed into the enormous and powerful steam locomotives, hauling the 20th Centuries of the present day.

Speed, safety, comfort and *economy* have been the watchwords of this development and any method which did not combine all of these fell by the wayside and was forgotten. The development of the street railway as an essential system of transportation resulted from the gathering of large numbers of people into confined areas, the increasing dimensions of such areas and the necessity for speed, safety, comfort and economy in moving them from one section to another for industrial, commercial and social purposes. Many of us have seen the problem of this industry grow from one of transporting comparatively few each day to one of transporting over thirty millions every twenty four hours, or eleven billions per annum, or one hundred times the total population of this country each year. The money of our citizens invested in these enterprises has increased to over six billions of dollars, an amount equal to one-quarter of the total funded debt of the United States at the present time.

Electricity, and electricity alone, has made this great development possible. The horse drawn bus and the mule drawn car on rails gave way to the speedy, and comfortable electric railway car; the cities were gridironed with tracks; cities, towns, villages and hamlets were connected; improvements of all kinds kept pace until today we have in the United States a magnificent system of urban and interurban transportation. But our cities and towns are steadily and surely growing and transportation facilities must be extended and increased.

What of the future? History shows that the street railway, and by that is meant all forms of local trolley transportation, is absolutely essential to our economic life. Its facilities are used largely by the wage earners and, hence, must be furnished at a price within the user's means. Electricity will propel cars per unit of transportation more economically than any other form of motive power, consistent with the speed and comfort obtained. However, the electric railway must have tracks for its cars. The investment in tracks is large and this cost distributed to the passenger is material in amount, especially in sparsely settled communities. However, with electric railways following main arteries of travel, or in thickly populated areas the amount of the track investment charge distributed to each passenger is small. For heavy and frequent traffic no other form of transportation has approached the electric railway.

But what of the claims made by the advocates of transportation by gasoline vehicles? Busses were operated years ago by animal power and were discarded. They are again made possible by the gasoline motive power and by the hard surface highways. The last is, however, the compelling reason. Let us assume that they are capable of handling the transportation of a reasonably large city, although recent experiments have demonstrated its impossibility. They are no more comfortable than a street car, they have no greater speed, they are not as safe, and above all they are less economical in operation, than a street car of the same carrying capacity. The cost of labor, machinery and supplies are not material in the comparison as such costs affect both. In spite of the prevalence of the jitney, in spite of the claims of motor bus manufacturers, and in spite of the clamor of those who for political or other reasons are plotting the ruin of existing local transportation systems, electric transportation upon rails remains the cheapest, the most reliable and the most convenient method of mass transportation that now exists, and there is no indication that it is to be supplanted in the future.

When all costs of service are assessed, the electric railway shows a substantial margin of economy over the motor bus, and it is only because the public is assuming as public charges a substantial portion of the costs of motor bus operation, while at the same time levying against the electric railway charges that are totally unconnected with its operation, that even a pretense of lower bus cost is possible. The bus, whatever its motive power, on account of its lack of need of tracks, is and has a function to perform in the great scheme of transportation. Its field is in areas of light traffic and extensions of routes which will not warrant the heavy investment in tracks. However, the gasoline bus is not the bus that will play a necessary and satisfactory part in the facilities of the future. It will be some form of electrically-propelled bus and will not have the odorous discomforts to passengers and the excessively high maintenance costs.

The only other competitor of the electric street car is the individually-owned automobile and that is not a competitor in the strict sense of the word. The owner of the automobile ceases to require the car ser-

vice. In the smaller communities the loss of patronage so occasioned is of considerable amount and vital to the success of the electric railway system. The railway business is exactly the same as an industrial enterprise, the product, which in this case is transportation, must exceed some certain percent of its productive capacity or there will be no return to the investor. Already street railways have been abandoned in some of the smaller communities because they have become economically impossible.

From a strictly business standpoint, the electric railways are emerging from a period of business, social and industrial upheaval, better acquainted with their own powers and possibilities and with better knowledge of their own costs. They have passed from the stage of experimentation to one of sound business production and are now on a firm foundation for future operation and expansion.

Turning to the consideration of another phase of the development:—No private enterprise furnishing service to the individual or public can succeed or continue, except by Government subsidy, unless the income exceeds the expenses. In the earlier days, communities and officials thereof welcomed with open arms the electric railway builder and offered him many inducements. Railways were built and became at once successful financially, whereupon there was a rush of building which became so keen that there was created an opportunity for governing officials to impose or withhold restrictions and conditions in permits or franchises either for their own personal benefit or for the supposed protection of the people. Unwisely many railway builders accepted conditions which were unjustified in law and equity and which later became too burdensome. During these years, partly due to the methods pursued by the railway operators themselves, but mostly due to the attempts on the part of unscrupulous office holders and candidates for office to make political capital, there grew up an attitude of hostility to public service companies on the part of the public. Demagogues told the public that it was being unjustly treated and the public believed them. Legislation was resorted to and, in an attempt to punish the railways, public service commissions were created to protect the public. These commissions soon found that in most cases the railways themselves needed the protection from a public, which was unwittingly, and from governing officials, who were viciously, asking more than was fair and just. The work of the various regulating commissions on the whole has been salutary, constructive and particularly productive of a better understanding of the questions involved.

The great war came with its disruptions and suddenly the railways and the public came face to face with the fact that this great and essential industry might collapse and be lost. State commissions, the Presidential commission, and courts, legislatures, financiers, railway owners and investors, the press and the public joined with one accord in thoughtfully studying the questions involved. It was not to be wondered at for this industry is so vital to the economic and social life of our communities, and six billion dollars of invested savings were at stake.

What has been the result of all this agitation and investigation?

In the first place it has been demonstrated that the electric railway as a means of local transportation is an absolute necessity and must be protected and fostered.

In the second place, the public has been educated quite largely as to the facts and principles involved and consequently it is willing to accord fair treatment which has taken the form of consents in many communities for higher rates of fare.

In the third place, the regulating bodies have found that the public and the courts require them to protect property rights and preserve the industry for the people by fair and constructive treatment of all such questions.

In the fourth place, the courts have been called upon to determine many questions not heretofore passed upon and such decisions have shown that property and invested capital of public service railways cannot be ruthlessly destroyed or dissipated by the malicious acts of politicians.

In the fifth place, the public, the regulating bodies and the courts are realizing and enunciating the principle that the rate of fare depends upon many conditions and that the impositions of unfair burdens which tend to increase that rate are discriminatory as affecting the car rider. The car riders have found that they are paying the bills and are insisting that they be not called upon to bear burdens which are not related in any way to the service they receive.

In the sixth place, the owners and operators of electric railways know their strength and their weakness, and appreciate as never before the solidity of the industry's foundation and structure.

In the seventh place, all, or nearly all, now realize that it is for the benefit of all that the street railway industry shall still continue to be fostered, developed, owned and operated by private capital. Municipal ownership is not popular with the sensible American public.

The one great question which confronts the industry today is that of financing maturing obligations and providing funds for future extensions of tracks and equipment to meet the needs of the public. Such funds must be obtained from a cautious investor who has absolute control over his investment acts. A true picture can be painted which must be so attractive that he cannot withhold his aid. Here is an industry which has a product which must always be used and in ever-increasing quantities, an industry which has been through the fiery furnace of the war conditions and emerges purified, justified and protected as no ordinary business industry in our history. Mistakes in any industry have been and always will be made, but the basic principles are the true test, the business of the

street railway always goes on in prosperity or adversity and while the price of its securities may go down in times of world upheavals, yet its path is not strewn with the junk heaps of many other forms of industrial enterprises. The electric railway as the main and dependable system of urban transportation is and will remain supreme, the bus will occupy a secondary or auxiliary position as a part of the main system and the present piratical operation will disappear. Furthermore, the gasoline bus except for sporadic operations will be laid aside and the electric motor bus as an integral adjunct to the electric railway will find its proper sphere.

The Problem of Mass Transportation

EDWARD DANA
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A THIRD of a century ago the phrase "Mass Transportation" would certainly have had an unfamiliar sound. Today one visualizes at once the size of the problem which is involved. The technical advance during this period of time in the history of urban transportation has been most varied and has engaged the attention of many minds.

The street railway was to a great extent the agency which created the problem of mass transportation, and today we ask how that agency can best be adapted to this purpose. The history of electric traction is almost as varied as are the communities which it serves. Local conditions, geographical as well as psychological, have determined the trend of development of each of the many local systems. We have today urban, suburban, interurban, as well as overhead and underground rapid transit systems; each in its own way striving to function so as best to meet the needs of its locality.

It is a question whether it is possible, or worth while, to attempt to arrive at the best solution of mass transportation, and thus set up a theoretically perfect unit which in all human probability never could be attained. Certainly such an ideal would not fit nicely the local requirements of communities so entirely different in character and vastly different as to size and rapidity of growth. Out of the hard earned experience of the past, however, has come knowledge which should be utilized wherever possible in order to permit existing systems to function efficiently and satisfactorily and to permit new systems or extensions to be based upon a somewhat more satisfactory foundation than much of the expansion of the past.

It is probably true that operating costs of urban properties will, for some time to come at least, remain relatively high and that satisfactory service and efficient operation will require an effort to increase the load factor of travel and, without sacrificing flexibility of service, will necessitate handling passenger traffic more in bulk than was done in the early period.

In most cities there is a well defined area, usually known as the "Delivery District." Modern building construction has greatly increased the number of individuals and consequently the volume of business that can be transacted within this area. In most large cities it would be a physical impossibility during the maximum hour to transport the volume of traffic which offers itself entirely on the surface and by a multiplicity of routes. Surface congestion would result. Irregular spacing and loading of individual cars attempting to transport people reasonably near their destination would cause slow movement and long waits for individual routes.

Elevated structures and subways permit concentration of traffic and by increasing the load factor thus permit economical handling of large volumes of people. The initial cost of these are great and they can never be justified for the operation of single cars. The increased capacity for single car operation is no greater than a reserved space on a highway. Efficient and satisfactory service can come only by the operation of trains of several units at frequent intervals.

When rapid transit thoroughfares, so-called, become a necessity, there comes a moment when the greatest consideration must be given to a comprehensive planning for the growth of the future mass transportation of the city. There are today examples of expensive construction of this character—ill-advised and serving no useful purpose in the future plans. Stations have been constructed to satisfy the political ends of those advocating them without regard for their need or effect upon the mass transportation of the system of which they form a part. When the important step of rapid transit thoroughfares has been taken, development should henceforth be made along the lines embarked upon and the future molded step by step.

In the early days, people were in the habit of riding from their front doors to their place of business. While transferring is by no means an ideal pastime, it becomes a necessary evil in the economical handling of mass transportation. Rapid transit thoroughfares ought to be constructed to transport large volumes of traffic between termini from which it can be distributed further over a wider area by different types of service best adapted to the particular volume of traffic.

In Boston an average of 972 000 passengers are carried throughout the year on week-days, on 459 miles of active track on the surface, in the subways and on the elevated. Approximately twelve percent of the active mileage is in elevated or subway rapid transit lines, and over this twelve percent of mileage eighty percent of the daily travel is distributed.

Unless the load factor of rapid transit lines is given attention in this respect, a co-ordinated economical transportation system cannot be constructed, as there would exist much duplication and consequent waste expense. In other words, as soon as such an artery has been placed in operation, other lines should not be operated in competition with it, but efforts

should be made to concentrate traffic by increasing its use.

It has already been proven that the extension of surface lines into growing territory before there is sufficient justification has seriously hampered many a property. Similarly, the construction of rapid transit arteries paralleling territory previously served by surface lines, with a capacity greatly in excess of the immediate use and waiting for traffic to develop (which in time of course it will) means in the meantime an even greater burden.

Given a comprehensive plan for the rapid transit arteries of an urban community of large size, the development of the secondary so-called feeder lines offers opportunity for a wide variety of treatment. These lines and their arrangement call for constant study and readjustment in order to provide speed and frequency. Large type motor cars, motor and trailer units, three-car trains, safety cars, motor bus or trackless trolley units offer a variety, the choice of which must be governed by the locality served.

It is quite obvious that tributary territory, where there is no element of congestion, cannot grow as readily by the application of the principle of mass transportation as by an effort to provide frequent, rapid and comfortable service to and from terminals of rapid transit thoroughfares; and the load factor of rapid transit arteries can be increased only by the development of tributary territory.

It is fair to conclude that rapid transit thoroughfares, either subway or elevated, are only warranted where traffic can be concentrated in sufficient volume to call for operation of trains at fairly frequent intervals. Such concentration can be obtained by the discontinuance of parallel surface lines, thereby removing street congestion, and the development of tributary territory, the load being brought in and transferred at terminals. This tributary territory in every case presents a problem in which local conditions will determine the degree of mass transportation which can best be employed.

The Outlook for the Next Five Years

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IN THE DARK DAYS of 1918 and 1919 the writer had occasion to read a number of papers and take part in many discussions concerning the then extremely perilous situation affecting urban transportation companies. In all of these discussions, there was an effort to be optimistic, although at times it seemed as if optimism was out of place and the future held little encouragement. This viewpoint was based on the fundamental facts that nothing had at any time been devised to take the place of the electric street railway in our large cities; that transportation was absolutely essential to the growth and well being of every city, and that what was essential and necessary must and would be preserved and supported. Our civilization cannot exist without the essentials.

The reversal of the causes which brought about almost complete disruption of the transportation industry in the United States will work for its revival. Only the essential nature of the street railway business has kept it alive in the past four years. It simply had to go on, and it did, at the expense of those who had invested some four billions of dollars, that the citizens of the United States might have transportation facilities. Wages and materials doubled in price until at the peak it cost from \$2.25 to \$2.50 to buy what one dollar used to do in pre-war days. The average increase in expenses was easily 125 percent; whereas, the average increase in fare was certainly not over 50 percent, although in some few cases 100 percent increase was given. Furthermore, fare increases were not contemporaneous with the increase in expense, due to the immobility of governing bodies and the reluctance of commissions to increase fares. In some cases bankruptcy was reached before relief was given. Other companies were able to weather the storm without being forced to the courts. They were those favorably situated, with large reserves, or in states where the commissions acted promptly to relieve the situation. Many of the largest companies however, in the end were forced into receiverships, in order to make possible a continuation of service and to protect their owners. One at least has suspended operation. In addition to increased expenses, there was a recurrence of jitney competition, which in many cities has been equally responsible, with high prices, for bankruptcy. This was due in large part to higher street car fares, which made it possible for jitneys again to compete with some measure of success.

The essential nature of the industry has been emphatically demonstrated in Bridgeport, Connecticut; Toledo, Ohio; and Des Moines, Iowa. In all of these cities street railway service was suspended. Each is convinced that jitney and motor bus transportation cannot supplant the service given by the street railway. In Bridgeport, after six weeks of suspension, with every opportunity given to the entire jitney association of the State of Connecticut to show what could be done, the people decided that they wanted the electric cars returned. The most recent example is Des Moines, where at this writing there has been no car service for three weeks. Motor busses and jitneys have been unable to meet the demands of the public, merchants have suffered a loss of business and at the present an effort is being made to have the courts order a resumption of car service.

The industry today, although there are several lean years ahead of it, after credit has been restored again will come into its own. The five cent fare is no more. The biggest handicap with which the business had to contend has been removed, and never again will it have

to suffer the results of an inflexible, fixed price for its product regardless of production costs. Various rates of fare the country over have been established and, although there will be reductions, they will be made more slowly than were the increases and there will be a closer relation between the cost of service and fare reductions. The initiative and the burden of proof will not be upon the railways. The position of the industry in this respect has been much strengthened by commission and court decisions relative to the rate of return; and, before fares are reduced, it will be necessary to show that excessive earnings are being made under the present rates.

Furthermore, the public has been better educated to the needs of utilities. The widespread publicity given to street railway matters in every city, due to local problems, and the necessity for fare increases, has awakened the public to the necessity of dealing more liberally with transportation companies. The steam railway situation, the President's Committee, the investigation of local chambers of commerce have all tended to waken the public conscience.

Material prices and labor are descending slowly to a more normal level. In the past year there have been decided reductions. This is especially true of coal and steel products. There has been approximately 10 percent reduction in street railway labor costs in the past year, and there will be further reductions, although it is doubtful if labor will ever again reach the pre-war level. Unrestricted jitney competition is lessening and the necessity for regulation has become apparent to every municipality. The examples of Bridgeport and Des Moines have fairly well proven that two systems of transportation cannot successfully exist together and in competition. There has been a let-up in the automobile industry and to some extent a less widespread use of the private automobile.

Management has improved during the war period. Necessity has been the mother of invention and lessons of strict economy which were learned will, without doubt, have a salutary effect on future operations. A better class of employes has entered the business, attracted by high wages paid in the past three years. This has been reflected in better transportation, more courteous and careful employes.

The great problem now confronting the industry is the difficult and almost insurmountable one of establishing credit for new capital imperatively essential for extensions, improvements and the retirement of maturing securities. A year ago, it was estimated that at least three hundred million dollars was then needed for immediate improvement, and this figure is certainly not less today. In addition, millions of dollars of long term bonds and short time notes are maturing and demand immediate refinancing. Although operating problems are becoming easier and earnings will doubtless gradually become better, this phase of the situation is one that will demand the best thought of the industry.

The financial situation has not turned for the better and probably will not for several years. Most of the long term bonds now or presently maturing were sold under extremely favorable conditions. There was then an active market for utility investments and long term issues were easily underwritten on a five, five and a half and six percent basis. The industry was extending, wages and materials were low and, because of cheap money, good net earnings were shown and dividends paid. Traction properties, however, were limping even prior to the war, and many of them were able to continue dividend payments only because of the low rates on their long term debt.

At present, unfortunately, issues are maturing and capital improvements are imperative under extremely unfavorable conditions. The investing public has been frightened away from the utility market, at least from street railway securities. Net earnings either do not exist or are inadequate. There is an extremely tight money market with no prospects of easing up for some time. This means that immediate financing must be through short term issues, for which exorbitant rates are charged. It will, therefore, take some years of good earnings, favorable public attitude and falling material markets before street railway issues will again become attractive to the investing public.

To secure the proper public attitude, service must be better than ever before. For high fare and better treatment the public expects and demands the best quality of utility service. The increasing competition of the busses and its threatening extension is an impelling reason in addition why there must be no let-up in the service given. Service is a comprehensive word and means many things. It means adequate cars, well lighted, well cleaned and well maintained. It means proper loading standards. It means well trained, courteous and efficient employes. But, in addition, it means that the local traction company must be prepared to extend its service to meet growing demands of the city, and to provide traction facilities in advance of these demands. It means keeping the property in condition to render a proper public service. All these things require money for capital improvements.

Upon the management is placed a three-fold obligation: that of adequate service to the public, attractive wages to employes, and a good return to the investor. As the matter stands today only one of these requirements is being met, that is, the wages now being paid. The investor is suffering and there has not been for the past three years a possibility of providing the capital improvements necessary to render the character of service that must be maintained.

The outlook then for the next five years is one of hard, unremitting drudgery for the operator, before the industry is again attractive to the investing public. This very fact, however, brings us back to the original proposition—street railways are essential and, being essential, they will be supported. Many things are now working together for the benefit of the industry and

when capital finds that the street railway business is on a more permanent basis, and after there has been an uninterrupted period of several years' favorable earnings, it will again become an attractive field for the investor, an active market for the manufacturer and a more satisfactory and attractive field for the operator.

The Development of Rapid Transit Lines

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And Chicago North Shore & Milwaukee Railroad

In presenting my views, some consideration will be given to the subject of electrification of steam railroads, first because the greatest strides in electric railroad construction in the next decade or so will be in that branch of transportation, and secondly because the electrification of the steam railroads will have a decided effect on the electric railway industry proper. Most people consider the latter as something quite distinct from electrified steam railroads, but undoubtedly the two will become more closely inter-connected as time goes on. The views here expressed necessarily are those of one more acquainted with railroad operations in and adjacent to large cities. However, there are certain fundamental thoughts that can be applied to the properties in small towns and to the lighter interurban properties.

One particular outside factor must be taken into account, i.e., the gasoline-propelled vehicle as a common carrier of both passengers and freight operating in our city streets and rural highways. Privately-owned gasoline-propelled vehicles have taken considerable traffic from both the electric and steam railroads, and must be given consideration in traffic calculations.

The problem of the transportation man will be to co-ordinate the electric railway, the gasoline carrier and the electrified steam railroad, so that each will fit into its proper place and perform the character of service for which it is best adapted. Common ownership of all means of transportation seems neither possible nor desirable, so that the harmonizing of the various factors must be accomplished through proper public regulation, if the economic waste due to duplication of service is to be avoided and the public given the most efficient service possible at the lowest possible cost.

The greatest development in local transportation, aside from the electrifying of steam terminals, in our large cities in the next few years will take the form of rapid transit lines, removed from the surface of the streets, rather than the extensive building of surface lines. The constantly increasing congestion in city streets, due to the use of the gasoline-propelled vehicle and the steadily increasing demand of the public for greater speed in transit, will make the construction of more rapid transit lines imperative. This development of rapid transit lines will probably be in the nature of subways in thickly congested city areas and elevated railways in the outlying sections. While the cost of construction of both subways and elevated lines necessarily will be high, the delays occasioned to all forms of traffic in our city streets, if measured in terms of dollars and cents, will compel the building of rapid transit lines, regardless of the initial cost.

It does not seem probable that sufficient private capital will be found to finance rapid transit lines on the scale required to meet the demands of the public. It is questionable if any one source will be found to finance such undertakings, so that the great cost of construction is likely to be met partly by assessment on the property directly benefited, partly by the municipality or municipalities in which the lines will operate and partly by private capital. With the growth of rapid transit lines, the tendency of the people will be to live farther and farther from the congested areas, so that the local transportation companies of the future will be required to give a service similar to the suburban service now supplied by the steam railroads and by interurban electric railroads.

The problem of electric railways, from the operating standpoint, is to utilize their track investment to a greater degree than is now being done, or indeed, than is possible under existing conditions. More people must be carried per mile of track operated with less congestion and lower operating costs. In other words, we must have a more efficient use of track capacity. To accomplish this it may be found necessary to abandon certain routes and to use other routes more intensively by means of trailers or double-deck cars. Also more passengers must be carried per unit of car weight and per unit of platform labor than at present.

The question of whether a given piece of track is justified or not will certainly be brought home to the operator when it is found necessary to put in a considerable amount of money in the reconstruction of that piece of track. It may be that the car operation is efficient and economical from the point of view of maintenance of equipment, power, and platform labor, but if the traffic does not justify a sufficient number of car-miles then the reconstruction and maintenance of the track may be prohibitive, in which case it should be removed and the service abandoned in favor of other means of transportation. A considerable number of loaded car-miles per mile of track is required to justify the cost of track construction or reconstruction. The advantage of the gasoline-propelled vehicle or trackless trolley is apparent, in that it does not require a frequent interval service in order to pay for a heavy investment in track. Again, if a given route does not work out satisfactorily financially, another route may be selected without losing a large investment.

It may safely be assumed that the electrification of steam railroad terminals within our large cities will be accomplished within a few years. The elimination of the dirt, smoke, cinders and noise, inseparable from

steam locomotive operation, is being demanded with increasing insistence. The answer, of course, is electrification. The problem of electrification of steam railroad terminals is less serious than it seemed a few years ago. There is hardly a large city, where the change is contemplated, that the required amount of power cannot be furnished by the local central station company at less cost than the railroad could produce it. The increased terminal track capacity of electric operation over steam operation is so well known and firmly established that it is not necessary to discuss it. But unless the electrified steam railroads giving a suburban passenger service are co-ordinated with the rapid transit electric lines giving a similar service, the increased terminal track facilities may easily be absorbed by the rapid increase in suburban traffic, bringing the steam railroads to a point where more track capacity must be secured at a tremendous expenditure of capital, in order to provide for the long distance trains. The peak of through train and the peak of suburban train traffic is often co-incident. Suburban business has been unprofitable and probably will always continue to be so. There is, however, no reason why the electrified steam railroads should not use the rapid transit line tracks as entrances into cities, at least for some of their trains. They should further make provision for diverting their suburban business, when it becomes burdensome, to the rapid transit lines which are there primarily to perform that class of service.

The interurban railroad that is going to live and prosper must, give a much higher class of service than some of them have done in the past. The type of interurban which is built on highways or partially on private right of way and, due to engineering faults or to location, is unable to give a high-speed first-class service, will sooner or later have to be improved or scrapped. The public has become educated to new standards, both as to speed and comfort, through the use of the automobile. The old-time inferior service given by some interurban roads will not meet the needs of the public. Particularly is this true where such interurban roads are in competition with steam lines and paralleled by good highways.

The gasoline-propelled vehicle of today is in a position somewhat similar to the electric street car in the early days. That its development will follow the lines of the electric railway seems probable. Large operating companies will be organized and recognized as public carriers, coming under the same public regulation to which other transportation agencies are subject. Operating costs will be analyzed, due regard being given to the wear and tear on public streets and highways, and taxes apportioned accordingly. When that has been accomplished and the gasoline-propelled vehicle put in its proper place, it will be found to be a valuable adjunct in the general scheme of transportation. But the gasoline-propelled vehicle must be a part of a properly co-ordinated transportation system and not an independent factor. It will have a field of its own. As the principal function of the steam road must be the long-distance haul of both passengers and freight and the chief function of the electric rapid transit line the intermediate-haul, so the gasoline propelled vehicle will find its proper place in the short-haul traffic field for both passengers and freight.

At present, the gasoline-propelled vehicle is given considerable advantage over the electric railway. The public pays for the building and maintenance of the thoroughfare over which it operates, so that such costs are not a charge on the service it performs, but that condition is not likely to last as the business becomes more fully developed. Placed on anything like an equal footing with the electric or the steam railroad, the gasoline-propelled vehicle would not be able to compete, except on very short-haul traffic. It will never be able to compete successfully with the electric car operating on rails for long-distance of even for intermediate-haul traffic.

Thus far only some of the operating features of the electric railway have been touched upon, but it might be well to glance at the financial side of the industry, which has been the most serious part of the question for a number of years. Although the industry is by no means out of the woods in a financial way, probably the most critical period has been passed.

The strangle-hold of the five-cent fare fetich, which in recent years has driven so many electric railway companies into receivership has been broken and, while office seeking politicians and circulation-seeking yellow newspapers occasionally clamor for the restoration of that strangle-hold, the great mass of the people have come to take a more reasonable and intelligent view of the situation than they ever had before. The people realize more clearly that electric railway service is a necessity in their daily lives and that the charge for such service must be based on what it costs. The watchword of the electric railway companies must be "Service," for it is service that the public demands. If the public is given the right character of service, it will be found willing to pay a fair and reasonable price for that service.

Futures

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THERE is much speculation as to the future of the electric railroads. Having formerly been profitable enterprises and as a class being so no longer, those interested wonder whether electric railway securities will continue on the down grade or whether they will come back.

In the beginning, when the electric motor displaced the street car mule, it offered to the public a fundamental advantage of tremendous value, i. e. greatly increased speed of transportation. The trolley

car then became the most rapid means of getting about town and the enterprising pioneers of the industry, being unhampered by regulation, soon capitalized this advantage and with great rapidity built up a tremendous industry in a comparatively short period of time. Everyone is familiar with the subsequent decline of the industry due to various and sundry burdens of increased expense, and to the limitation of fares, but along with this change came another and more fundamental modification, namely, that brought about by the automobile.

The trolley car is now no longer the speediest vehicle for urban transportation. In fact it has been so far surpassed by the automobile that the trolley officials themselves seldom use it for getting about over their own lines. It is conceivable, even if perhaps unlikely, that the laws prescribing regulation and those respecting certain burdens of expense may be so modified as to leave the trolley roads unhampered to work out their own salvation, but the automobile is here to stay and must be reckoned with as a permanent competitor. This competition may perhaps be broadly subdivided into four classes,—

1—The jitney
2—The organized bus line
3—The taxicab
4—The private motor car.

The jitney seems to have been a more or less virulent disease which is rapidly running its course because its basis of operation was unsound. That is to say, the jitney was originally free from burdensome legal restrictions and in addition the jitney driver did not know what his service was costing. Although the jitney probably will never be altogether eliminated, street railway men as a class undoubtedly feel that, as a fatal trolley disease, this pest is rapidly fading. Public authorities are generally coming to recognize that, for their own protection, jitneys should be treated as common carriers and therefore subject to the same control as other common carriers, and this recognition, reinforced by the firm and just insistence of some trolley companies that either the jitneys be controlled or they themselves would go out of business, has brought about the cure.

Some months since the *Electric Railway Journal* published a series of articles giving statistics compiled from the records of a large number of bus companies, which showed anything but favorable financial results. While bus companies will no doubt continue, and while the bus has a distinct field of usefulness, it does not possess the most effective weapon which other motor cars use against the trolley, i.e. increased speed. It is a cumbersome, lumbering, slow moving affair, which obstructs traffic more than other passenger vehicles, is quite inadequate to handle heavy traffic and moveover has a very high maintenance and operating cost. In view of these facts, it seems clear that the fundamental handicaps of bus service will prevent it from ever substantially replacing that offered by the trolley.

The taxicab and the private car compete on an entirely different basis. They do not attempt to handle all the traffic. They do not attempt to compete in price. On the contrary they cater entirely to those who want greatly increased speed and comfort and are willing to pay accordingly. Their use has gone forward by leaps and bounds and there is little doubt but that most of the people who use them were formerly trolley car patrons and would still be if the present facilities were not available.

Admitting this permanent depletion in trolley patronage and recognizing the numerous and increasing number of private cars and taxicabs, it is still an undoubtedly safe assumption that this number will never constitute more than a relatively small percentage of the total population. If this assumption be correct, then all the changes in fundamental conditions enumerated above still leave a substantial field for the trolley.

In the past the trolley has performed two distinct services in its community. First, it furnished public transportation, and second, through the medium of extensions into suburban districts, many of them not yet having a supporting density of population, it induced a migration of the people to those sparsely settled districts with the ultimate result of municipal extension, increased taxable values, dilution of population density in the centers and sometimes incidentally the creation of profitable traffic for the trolleys. Regulation has recognized and permitted the first function above but has taken no account whatever of the second, consequently surburban trolley building in anticipation of future traffic has long since stopped.

In forecasting the future of the trolleys, there seems to be little probability that they will ever again be a material factor in city extension. The necessity for their existence as already established may, and probably will be, sufficiently appreciated to secure laws that will permit an interest yield that will make their securities reasonably safe for investors, but without any chance for handsome profits. Without this chance capital will not take the risk involved in building ahead of the demand. We may expect to approach more and more nearly to the situation which has existed for a long time in England, where the trolleys are operated only through congested districts, where they are seldom if ever extended, and where they are gradually but surely becoming less and less of a factor in the total transportation problem.

The Trackless Trolley or Trolley Bus

THOS. S. WHEELWRIGHT,
President,
Virginia Railway & Power Company

SINCE July 1, successful demonstrations of the trackless trolley have been made in Richmond and Norfolk, Virginia, in the smooth-paved residential districts where the right to operate track lines has been denied. During the demonstrations, the

public as well as public officials of these two cities were most generous in their approval of this new method of transportation. In their references to the new trollibus, many of its enthusiasts have carelessly remarked that it is a *revolution* of the present street railway system—which is all wrong. It is an evolution; not a revolution! Note the definitions given of the two terms by the Standard Dictionary:—

EVOLUTION: The act or process of evolving; development or growth, as the evolution of a plan or system.

REVOLUTION: An extensive or radical and usually somewhat sudden change in anything. A movement involving the overthrow or repudiation of an existing government, etc.

It will be noted that evolution connotes growth and development whereas revolution suggests destruction by radical change, repudiation or overthrow. Therefore, applying these definitions, it will be seen that the trackless trolley or trolley bus is an evolution rather than a revolution. It is a means for the development of the present street railway system, whereby transportation service can be made to grow and expand with the development of the community. The use of the term "revolution" in connection with the trackless trolley has already fixed in the minds of some the idea of destruction because frequently the question is asked whether the company plans to pull up its present tracks and substitute trackless transportation.

Neither Richmond nor Norfolk, nor any other city, is much concerned about changing the mode of its transportation where it already exists. What concerns, or rather what should concern, every growing community is how to keep the transportation lines it already has and how to get service into those sections not now served. That's what concerns these Virginia cities.

Like the evolution of street paving from cobblestone to Belgian block and from Belgian block to asphalt and concrete, so, too, must there be an evolution of transportation and other facilities to meet the modern need. The electric street railway is in keeping with the stone and other rough paving, because both connote noise. With the smooth-paving, however, comes the demand for a transportation service that will be in keeping with the quiet and comfort suggested by the new smooth paving. To meet this demand and desire, the trolley bus has been especially designed for operation in those smooth-paved sections where regular transportation service is not now available. Its function will be to reach out into those unserved sections.

Thus the trolley bus is an evolution or development, not a revolution or overthrow. It is a means by which the electric trolley can be made a greater factor in community growth of the future than it has ever been in the past.

Outlook for the Electric Railway Industry

HENRY A. BLAIR,
Chairman Board of Operation,
Chicago Surface Lines

THE ELECTRIC railway is the public service facility most intimately connected with the everyday life of urban inhabitants of the United States. The necessity for its continued operation is paramount in importance. When local interruption of the service occurs in marked degree, it has a paralyzing effect upon the economic, social and industrial life of the community, and when from any cause these interruptive conditions against the normal functioning of this essential service become general, the paralyzing effect extends to the economic, social and industrial life of the nation.

Development of the street railway business of the country has been gradual from small beginnings with slow moving, diminutive vehicles drawn by a single horse to larger two horse cars, then the faster cable railway with larger and better cars operated in trains, and finally the now highly perfected electric railway systems requiring a capital expenditure per mile of track more than eight times the investment required to produce the original horse car lines, and supplying rides, until quite recently, for the same unit fare for distances ten times greater than the maximum distance traveled by the horse car.

In the early days of promotion in the street railway business, those men of vision, courage, and the ability to actualize their conception of a useful public service, were looked upon as public benefactors; they were given encouragement and co-operation of the communities where local transportation was proposed and from small beginnings the development of the service and expansion of the communities were rapid. In the beginning, after the demand for service became sufficient to establish the necessity for the street rail way and signs were evident that the business was or would become commercially profitable, competing companies were organized and obtained operating rights in the same community in almost all places where street railways had been installed.

Urban transportation, being a natural monopoly, the consequences of duplication of service, duplication of investment and operating expenses soon began to contract the margin between income and outgo to an extent that threatened financial disaster to the industry. Then, in obedience to that natural law of monopoly in public service and in order to remove the danger which then threatened the business, managers of street railways sought the safe haven of consolidation of the competing lines so that the business might be conducted in harmony with a sane plan of progression and in the best interest of the public and the operating corporations.

Through the process of consolidation of compet-

ing companies and the expansion of the railway systems, the companies naturally became larger and larger, and the capital represented by these operations involved many millions of dollars. As the communities expanded in population and area, the inhabitants became more and more dependent upon the services rendered by the street railway companies and, as these consolidated public service interests increased in magnitude and power, a field of exploitation was opened and invaded by unscrupulous promoters whose sole aim was the making of quick money, and by self-seeking, political interests who saw an opportunity for political advantage in advocating, in the name of the people, unreasonable demands, and creating public prejudice against the service corporations—all of which resulted in vital restriction of the rights and privileges of these operating companies, i. e., limited franchises, fixed fares, free transfers, the imposition of unjust burdens in the form of obligations to perform services of a public character which are distinctly functions of municipal government. These arbitrary restrictions, in addition to the constantly increasing cost of labor and materials, taken in connection with the inelastic fare requirements of franchises had, prior to the recent world war, created a financial situation in the street railway business that weakened the credit of the companies and made it difficult for them to raise the money constantly required for extensions and improvement of service, except at costs in the form of interest rates and discounts that were rapidly approaching the prohibitive stage.

Then came the world war with the accompanying violent increases in the cost of every element entering into the expense side of conducting street railway affairs without any compensating increase in the rates charged for service. As a result net earnings of the traction companies fell off and their already weakened credit was almost totally destroyed. Capital had to be secured to take care of maturing obligations and, as the margin of safety over interest requirements diminished, the risks attending investments in railway securities increased, and the companies have had to offer greater and greater inducements to attract necessary new capital which could be secured only at interest rates in many instances higher than the fixed rate of return allowed on the investment by franchise and other regulations.

During the last two years, some measure of relief has been obtained through orders of State Public Utilities Commissions, who have advanced rates after thorough investigation of the facts. These advances in rates, though helpful, have not altered the situation in regard to the lost credit of the street railway companies of the United States. Upon a proper solution of this question of credit rests the prosperity of the business and the adequacy of the service to the public.

The problems confronting the street railway industry are, in the last analysis, problems of the people. Their solution depends upon a complete understanding by the public of these problems as they now exist and the education of the people to the importance of the questions to be solved and the method of curing them. The prime factors in the solution of these problems are therefore:—

First, the creation of a sound and correct public sentiment with the eradication of a number of ideas that have come down from the past in the way of prejudices, such as, the belief that the industry considered as a whole is greatly over-capitalized and that the people are asked to pay return on excess capitalization, and that the present situation of the companies is the result of mismanagement or dishonesty.

Second, recognition that the street railway business must be solved on the basis of service and that there are mutual obligations on the part of the service companies and the public—on the part of the companies to render good service under proper and sane public regulations, on the part of the public to provide the revenue that will pay all the costs of the service, including a fair return upon the fair value of the property used and useful in rendering that service together with the necessary reserve funds to insure the upkeep of the utility.

Rates established on the fair value of the property bear no relation to the amount of capitalization. Special and earnest effort is required on the part of railway officials, state public utilities commissions and the courts to evolve, as nearly as can be, uniform methods for determining the fair value of public utilities for rate making purposes and, where the capitalization of companies exceeds the fair value as determined, readjustments should be undertaken to bring the par value of outstanding securities as near to the level of the established fair value as possible. Future extensions should be financed partially through the sale of stocks to create and maintain a constantly increasing margin between the outstanding mortgage securities and the established fair value of the properties.

That the essential public service supplied by the street railways must be continued is obvious. Unless there is established complete co-operation between the public and the privately-operated utility looking to the rehabilitation of the credit of the operating companies on some sound cost-of-service basis, these street railways will not be able to function properly and the alternative of public ownership and operation of them must be resorted to and all the costs of the service be provided directly through fares or indirectly through taxes. There can be no doubt as to which of these alternatives is economically sound and will be adopted by any correctly informed community.

Where cost-of-service contracts have been adopted, good service, a fair wage to employes, a fair return on capital and established credit have resulted. There is no single cost-of-service plan, which in its entirety can be applicable to every company or locality, or to all conditions. However, there are cer-

tain fundamental principles that will apply to almost every case and in so far as they are applicable the problems of the different localities and companies are alike and details that will harmonize with these fundamentals and will fit the local situation in each case, are entirely susceptible of being worked out and, therefore, the general applicability of the cost-of-service plan may be recognized.

Fundamentals that should underlie every cost-of-service plan are; indeterminate franchises, which reserve to the city the right of purchase; adequate public regulation supervising the service and safe-guarding the rights of the public; automatic adjustment of rates as the cost of the service fluctuates upward or downward; establishment of necessary reserve funds and a fair return upon a fair valuation of the property with some additional return dependent upon efficiency of management in keeping fare rates as low as possible. Contracts based upon these fundamental requirements will insure good service and will establish and maintain the credit of the corporations, place the securities of street railways in a position that will make them desirable as permanent investments and enable the companies to obtain, at a reasonable cost, the large sums of money that are required for capital investment to keep pace with the yearly demand for increased facilities and service.

If the public is to be supplied with the quality of street railway service to which it is entitled, the companies must be placed in a position which will enable them to go into the market and compete for the capital required to make extensions to their lines and provide the necessary equipment and other physical property. There is every reason to believe that the period of tight money in which the demand for capital will exceed the supply, which must be reflected in high charges for it, will be further prolonged. Investors cannot be coerced into putting their money into enterprises that do not offer a substantial degree of safety and future promise. In its present situation, the street railway industry does not offer that degree of safety and future promise that will attract capital. However, though a spirit of gloom has prevailed in the situation during the recent period of depression and of sore trial with which the public service enterprises throughout the country have been forced to contend, the outlook points to optimism rather than to pessimism.

There can be no prosperity without local transportation. The inherent good judgment of the people will prevail when all the essential facts regarding the street railway situation has been revealed to them. Then the utility companies will be accorded the co-operation of the public in bringing about a readjustment of street railway affairs that will be fair to both sides, stabilitating the credit of the service companies to the end that good service will be given to the public, fair wages to employes, and insurance of a fair return on invested capital until it shall be returned to its owners.

Dealing with the Public and Employees

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THE EXECUTIVE of a utility who would serve the public satisfactorily, has three interests to consider,—the invested capital, the public and the employee. The success of his company depends entirely on the co-ordination of the three. The following discussion deals with only two of these subjects, the public and the employee.

In the development of the utility business, the minds of the executive and operating departments must constantly give serious thought to the matter of dealing with the public and employees. The utility business is a natural monopoly and must be such to serve the public at the lowest possible rates consistent with good service. It is a simple mathematical proposition that a duplication of investment, brought about by competition, will add additional burdens on the public in higher rates to maintain the same. While the method employed in dealing with either the public or the employee, in a general way, is very much the same, yet these are two distinct problems.

The problem of dealing with the public, with respect to the operation and maintenance of a utility in a community or communities, as the case may be, is not at all perplexing. As in any other business, truthful dealing is the cardinal principle. In order to be always truthful in our dealing with the public, patience, tact and a thorough knowledge of our own business and the principles involved are required. The successful operator of a utility must not only be thoroughly trained in his particular field, but he must have a thorough knowledge of the community served, a broad personal acquaintance with the territory, a general knowledge of the particular problems peculiar to the territory served and keep in mind that the solution of *his* problem is the solution of the *community's* problem.

Service rendered the community should be as nearly perfect as it is possible to make it by human effort. The handling of complaints is a very delicate part of our business. To that official or employee delegated to handle complaints is also entrusted a grave responsibility with respect to the success of the property involved. A trivial complaint coming from the least influential person in a community can be likened to a snowball rolled by a school boy. As the complaint is carried from one person to another, it gathers volume and grows larger and larger and, like the snowball, finally becomes unmanageable. Perhaps the most perplexing problem is the diplomatic handling of complaints. How easily a telephone complaint from some outlying district can become general, augmented as it will be, by unfair critics and criticism. Utilities generally do not attach enough importance to their complaint departments in the employment of broadminded,

tactful students of human nature. Many very serious complaints, which finally reach the governing body of utilities, the public service commission or city council, begin in a very small way and, as a result of being treated as inconsequential or of being neglected by the service department, become highly aggrevated expressions of popular dissatisfaction.

No utility can continue popular with the people it serves or prosper financially without an open, fair-minded policy in its dealings. The public is beginning to learn its lesson with reference to utilities. The value of property in any community, for instance, is very largely affected by the kind of utilities which serves it and the value to the community can only be measured by the utility's ability to serve it. The public is also learning its lesson with reference to improvements and cost of operation. It can be said safely that the utilities of America, generally speaking, serve the public with better service at less cost than in any other country in the world. In the past, utilities have tried to serve the public in spite of unfair conditions and they have been handicapped by rates that were not in keeping with the value of the service.

Out of the great world's war, we have gleaned some very valuable lessons, and one of these lessons is the value of the service of the public utility in any given community. Two of the great problems of the utility operator today are to produce service for a fair return and to educate the community regarding the value of the service given.

There is no general cure for utility troubles. Each community must be dealt with individually with specific attention given to its peculiar topography. The whole situation can be summed up by saying that utilities may be successful if they will practice open, fair-minded dealing with the community served, thereby educating their customers in the problems of the company and especially in the importance of the benefits enjoyed.

The second phase of this question is that of dealing with the employees. Years ago we had a President whose hobby was duck hunting. A very close friend of Mr. Cleveland, in commenting on his fondness for hunting said he was unable to understand how any one could derive any pleasure from wading through marshy swamps in cold, biting winds, being upset in muddy water from a canoe, returning at night cold, wet and hungry. The late President listened patiently, as his friend pointed out all the disagreeable experiences incidental to duck hunting, and after the friend had concluded his argument, Mr. Cleveland, with sparkling eyes, replied—"Jim, duck hunters are like artists, they are born, not made." This particular story is apropos of the utility employee of today—he is born, not made. In taking new blood into an organization, care should be given to fix in the mind of the employee the peculiar problems, perplexities and duties which are automatically assumed.

Employees of utilities, from the lowest in rank to the highest, no matter what particular place they may occupy in the organization, are servants of the public. As servants of the public, we owe the public a duty, as well as the corporation we serve. In the selection of employees, or the replacing of employees of a utility, extreme care should be given to personal fitness; to filling their minds with the important fact that they are public servants and can materially add to the success of their employers; that their actions are regarded by the public as the immediate and direct reflection of the policies of the corporation.

In today's game of life, the problem of getting ahead in the world is as perplexing, and perhaps more so than at any other time in world's history. Men with ability, who enter the service of an up-to-date wide-awake utility organization, may always find room at the top. A policy of open, fair-minded dealing is applicable to the employee, as well as to the employer. The employee, however, should be impressed with the seriousness of the duties he undertakes. A wage should be paid employees that is in keeping with the service they are to perform. Many great organizations of this country have been built up by training their own men and this is particularly true of transportation companies. The training of men involves years of careful selection, patience and tact, and great care should be given to the promotion of trained employees to better positions created or made vacant from various causes. Public service corporations can only be successful to the extent that they are represented by trained, efficient men.

The Relation of the Electric Railway to the Community

ARTHUR W. THOMPSON
President, Philadelphia Company
Pittsburgh, Pa.

It has been well said that transportation is the measure of civilization.

PROGRESS under our form of government is based on the idea of individual liberty which recognizes limitations to individual freedom required by the general welfare. The printing press, the telegraph, the telephone, mail service, the moving picture, have all played their important parts in making clear the necessity for subordinating individual desires to the general welfare. But passenger transportation, which provides one of the most effective means of approaching human understanding in the most direct way—by personal contact between individuals and groups—has done more than all of these to promote the sound development of our country until it has become the best living place for the individual, and therefore the most powerful and prosperous nation on earth.

If some of us occasionally contemplate our past performances and present power with complete satisfaction we will not remain complaisant for long. Our

progress has been due to an increasing knowledge of affairs which affect the welfare of the average citizen and he is not going to continue satisfied with his present condition. He understands that real improvement in his own affairs is directly dependent upon the general welfare, and he is going to insist that others conduct themselves in accordance with the general welfare.

Industrial Development and Overcrowding—Along with passenger transportation development has come the crowding of industrial activities and population into small areas. The member of society upon whom civilization depends for its existence, the worker, has the most vital interest in the results of this overcrowding. By worker is meant one who does useful manual or mental work. Nearly everyone comes within this class. The average worker knows that by reasonably wise political, social and industrial leadership, his interests are served reasonably well.

This knowledge on his part and the actual conditions surrounding him, which everyone must admit are not reasonably good for large numbers of workers, make imperative some action to provide the opportunity at least for the worker to improve his condition. Most leaders of men realize that by providing broad opportunities for the betterment of the worker, they are best serving their own interests.

Leadership—Pauperizing efforts, making it appear that progress in improvement can be made only through the gracious bounty of the leaders, does more harm than good. Honest efforts of real leaders to establish organizations for the betterment of workers on sound economic foundations have helped considerably in some cases, but taking into account the requirements of the general situation, the results of these efforts have been comparatively meager.

Knowledge is power; the average worker is gaining more knowledge of matters which affect his interests every day. Therefore he is becoming more powerful in those affairs. The more knowledge he gains, the greater is his ability to secure wise leadership and steady improvement in his present condition. The average worker may not understand how his condition can be improved, but he knows when his leaders are honestly trying to keep in step with progressive development; and he is going to change leadership until he secures leaders who are wise enough to recognize that their best interests lie in his progressive improvement. By leaders is meant men who are in positions of influence over capital, labor, society or politics.

The Home and Social Progress—It is generally recognized that the home is the foundation of the nation. The average worker wants a good home for his family and himself, and is willing to work for it. A careful survey of the conditions existing in any of our large industrial centers will convince anyone that some radical change must be made in the living conditions of a great many workers, and also that improvement in these conditions is going to increase the value of the worker and his family to industry. This brings us up to the question of how to provide for the improvement of the home on a sound economic basis by a method which will yield a fair return for the time, effort and money expended on it. Attempting to give something for nothing or to get something for nothing can lead only to failure.

Co-operation—The answer seems obvious. There are practically unlimited areas of splendid residence territory within electric railway distance of our large industrial centers. No one of the elements interested, the employer, the community or the car rider can, by itself, support the cost of building and operating the facilities necessary to provide the opportunity for better homes. All elements are so greatly benefited that carrying the burden by any one of them means giving something for nothing. In many instances the employer is trying to improve conditions by providing better houses; but better houses in the same locations will not always answer, and better houses in better locations without the necessary transportation to make them available is no improvement. The employer must go a step farther and co-operate with the community and the car rider to provide better homes with the necessary transportation, and in that way increase the value of the worker, of the community and, therefore, of his own business.

Essential Nature of Street Railways—No facility has been developed which can compare with the electric railway in economy and comfort for hauling large numbers of people for comparatively long distances. Some other kind may be developed, but our problems are pressing for action and it is imperative that we proceed on the basis of our present knowledge and not wait in the hope that something better may turn up. The auto bus will undoubtedly develop as an ally of urban transportation systems, but the backbone of any such system in large communities must be the electric railway.

While the homing instinct is going to be the principal factor in the future success of the electric railway industry, there are other factors in the demand for its services that play a large part in the welfare of a community. The electric railway provides a better labor market both for employer and for employe. With effective street railway facilities, the employe may sell his services to any one of a number of employers and, on the other hand, the employer has a broader field in which to secure his help. A surplus of workers in one part of a community can be used to effect a deficit in another location, to the advantage of both sides—if the transportation facilities are effective.

Educational facilities, the vital factor in the sound progress of our country, may, by good transportation, be made available to increasing numbers of our present and future citizens. This is one of the most effective means of appealing to the better side of the worker—to give his children the opportunity for a broader endeavor.

The average worker is a better producer for his employer and a better citizen for his community if he frequently has the opportunity to get away and look at his work from a different angle. Along with recreation goes amusement. No one can deny the great advantage of a reasonable amount of amusement to any man and its beneficial effect on him and his family.

All of these advantages are, to a large extent, possible only by the use of electric railway service and an encouraging feature from our standpoint is that the average worker is willing to make a reasonable effort to secure all these advantages for himself and family, but the best thought is that for the money he spends in supporting this necessary utility, he gets in return a commensurately greater ability to earn. His enjoyment of life is limited only by his effort and his ability.

Increasing Future Prosperity—To sum up:—There is an urgent demand on the part of employer and employe in our cities for better employes and better living conditions. This demand must be met and it will be met. American communities can meet any emergency, as is shown by experience.

The best way in which it can be met is by the sound economic development of our electric railway facilities. This will require co-operation between the leaders of all elements, mutual understanding and fairness. Those who fail in leadership will be replaced by real leaders. The inevitable result will be a tremendous increase in the usefulness of electric railway facilities, and the consequent and necessary prosperity of the industry.

This cannot mean that every electric railway company in the country is going to grow and prosper. Some are confronted by insurmountable difficulties. However, the industry generally, by furnishing a supply of valuable service to meet a real demand at a fair price, is going to prosper. Its prosperity will be measured by the ability of its personnel to understand and inform the minds of the public and of the car riders regarding its service. In other words, its ability to produce and sell its service.

Illinois Pioneering in Public Relations

BERNARD J. MULLANEY
Director,
Illinois Committee on Public Utility Information

In two years the writer has attended six national conventions of public utility associations—one electric, two gas, one telephone and two electric railway conventions. All six have had two features in common; the subject of public relations in practically every address, paper and discussion, except in the strictly technical ones; and each convention has adjourned and left the subject of public relations about where it was when the convention met. This experience has bred a conviction that the Illinois Committee on Public Utility Information has developed the best plan yet devised for bettering public relations in the utility industry and a hope that exploitation of this Illinois plan may stimulate still wider application of it.

The "author" of the Illinois Committee on Public Utility Information is Samuel Insull. Speaking on "Some Present Problems of the Public Utilities," before the Illinois Gas Association in Chicago on March 19, 1919, Mr. Insull drew attention to certain impressive statistics of the utility industry, and added:—

> "Think what it will mean to us (the public utilities) if we can bring home, to the communities in which we operate, the significance of the figures I have just given you! Now, it is our special job to do just that; to get at our own employes, our own stockholders and bondholders, and our own customers. We ought to make it clear to them that rate making, in our business, is not a simple matter of fixing a flat price; that proper systems of rates cannot be worked out scientifically when politics enters; and that an enormous field for development will be opened, alike to industry and to ourselves, by proper systems of rates."

Five Insull company vice presidents met a little later under adjuration to "get something started." Representatives of both the Independent and Bell telephone interests also sat in. That was the beginning of the Illinois Committee on Public Utility Information. The Committee now has twenty-seven members representing all interests and all phases of the industry by nomination from the state electric, gas, electric railway and telephone associations, but its program is unchanged. That still is; "to conduct a systematic campaign for informing the public on the fundamentals, and particularly the economics, of the public utility industry." The committee aims to utilize all possible agencies legitimately and properly usable for its purposes.

When the committee celebrated its second anniversary last April it had passed the 5 000 000 mark in pieces of literature distributed. This literature, all helpful to the utility industry, was not merely scattered broadcast, but was definitely placed: with newspaper editors for themselves and their readers; with customers of public utilities; with business men, bankers, lawyers, employers (for their employes), teachers, preachers, librarians, students in colleges and high schools, mayors, members of city councils and village boards, public officials of all kinds and candidates for public office. Members of the legislature, for example, received informative matter on public utility questions, not after they were elected, but before they were even nominated.

Aside from this, the committee has standardized itself as an information source. Its help is constantly sought by newspapers wanting data pertinent to current news, by students facing a school debate or a thesis task, by lectures wanting to freshen up platform material, by writers of circular and advertising matter for investment houses and so on. Even members and attaches of utility regulatory bodies draw upon the committee's resources.

A brief summary of the routine work of the committee follows:—

> A news service goes regularly to the 900 newspapers in the state, about 150 of them dailies. The matter carried in this service is informative rather than argumentative, and has to

be interesting enough to be printed for its own sake.

Speakers bulletins are issued, each devoted to some phase of the utility industry, as for example; theory and practice of utility regulation; utility financing; utility rate making, etc. The bulletins furnish ample material to any intelligent person for sound talks on each subject and they have been widely used.

A bureau is operated to find engagements, before clubs, civic associations and so on, for dependable speakers on utility subjects. In nearly 100 cities, the bureau has also organized local utility managers to co-operate in promoting this public discussion.

Pertinent addresses and articles by important men, resolutions or other expressions by chambers of commerce and other bodies, exceptional editorials and the like, and special matter for customers, investors and employes, have been printed and circulated among special classes by hundreds of thousands.

More than 800 Illinois high schools are regularly furnished informative literature for class room, theme work and debating society use. This is of such character that the schools ask for it.

All local managers of gas, electric, telephone and traction companies receive copies of everything issued by the committee. By letter, by discussion at association meetings, and by reminders from higher executives, local managers are constantly stimulated to co-operate with one another and with the committee in all possible ways of reaching the public; and the ways of co-operating are mapped for them in considerable detail.

Educating is a slow process at best and the efficacy of any particular campaign is to be fairly judged only by cumulative results over a considerable period. But a few outstanding cicrumstances may suggest what the Illinois Committee believes it is accomplishing.

The state press uses the committee's news matter in quantity far beyond the most optimistic expectations. Evidence of absorption of utility facts by the editorial mind is widespread. Helpful editorials have appeared, literally by hundreds, where formerly there were none or only hostile ones. Results in this respect are so obvious that committee members who were sceptics in the beginning would not now think of stopping the work. It is noteworthy that the committee has not once been seriously accused, by newspaper, politician or utility-baiter, of trying to "propaganda-ize" the public.

In the summer of 1920, certain politicians started to make politics of the necessary rate increases which had been granted by the public utilities commission. Abolition of state regulation and reversion to extreme "home rule" were promised by one of the political factions. Citizens and civic bodies then began to take notice. The Illinois Chamber of Commerce (a federation of business associations in the leading cities) conducted a referendum; and the business sense of the state, by vote, declared for state regulation and against "home rule" in the ratio of 21 to 1. The legislature adjourned in June without abolishing state regulation. Again, whenever there is a utility association convention in Illinois, the newspapers print immeasurably more about it than they used to print information on the economics and problems of the industry. None of this used to get printed until our committee began educating the papers to recognize the utilities as a source of news.

Many hold that Illinois is now the best educated state in the union on the utility industry. Surely the process of educating it has been of some help to the customer-ownership campaigns by means of which the number of utility security holders in the state has been increased from 250 000 in 1919 to nearly 500 000 now—an impressive figure.

But the committee's work has been by no means wholly local in effect. It has been instrumental in the inauguration of similar work in Ohio, Indiana, Kentucky, Nebraska, Missouri, Iowa, Michigan, Wisconsin, Oklahoma, Arkansas, Georgia, the New England States, Colorado, New Mexico and Wyoming; and it has inspired the preliminary steps in New York, Kansas, Texas, California, Oregon, Minnesota, Florida, Tennessee and Alabama. Its literature has been at the service of other states and largely used. Its publications have been circulated literally from coast to coast.

Out of their two and a half years of experience, members of the Illinois Committee have come to certain definite conclusions. One is that really effective cultivation of public good will is a task for composite intelligence of the highest order; a task for technical skill and experience in this special field, plus the active assistance of the industry's ablest men.

Another conclusion is that effort to cultivate public good will for any particular branch of the utility industry—gas, electricity, telephone or traction—gains in effectiveness when it is part of a campaign for the whole industry, as under the Illinois plan. The appeal is for a great and all prevading industry instead of for a special interest. At the same time, a special appeal for gas or electricity or telephones or traction is in nowise weakened, but gains from the background and support furnished by the broader, general appeal.

Still another conclusion is that nationalized efforts in this field are ineffective when direction of them from one central point is attempted. Managers of the "war drives" all found that they could not get results that way. They had to organize regionally, by states, and by communities, and national control or supervision was only for co-ordinating and focusing the regional efforts.

The logic of these conclusions will be recognized some day by men at the head of the utility industry. They will then insist that the Illinois plan be put into operation in all states of the union, for the co-operative good of the entire utility industry, and with just enough national supervision to stimulate and encourage the weaker states and to co-ordinate and focus the work in all states. When that is done, you will have the machinery for getting action nationally upon any matter in which the utilities, or any group of them, may be interested. It may be a traction matter today, a gas matter tomorrow, an electric light and power matter the next day, a taxation matter the day following. No matter; the machinery will be equally efficacious for all. When that time comes, the Illinois com-

mittee will cheerfully contribute, for the common good, all that it has learned while doing the things which have been briefly sketched here.

The Standard Types of City Cars

The Country Really Needs to Meet Traffic Requirements

W. H. HEULINGS, Jr.
Vice President and Gen. Mgr. Sales,
The J. G. Brill Company

The ECONOMIC value of standardization in the production and maintenance of electric railway rolling stock is largely responsible for the present tendency toward the general use of certain standard types of city cars which have been developed and already extensively adopted. It might be said that this tendency toward standardization of car design is the result of changed conditions in the industry which make it imperative that advantage be taken of every opportunity to offset the high cost of operation and the competition developed within recent years by privately owned automobiles and irresponsible jitneys.

When in 1831 John Stephenson, the "daddy of the street railway car" created the first horse-drawn vehicle to be operated on rails he took as his model the then most popular type of vehicle for public transportation—the stage coach. This was the beginning of street railway car design and little was realized at that time of the development that was destined to follow. In those days the lack of a quick and convenient means of "annihilating" distances had retarded the growth of communities and "mass transportation" was a term unknown to the men who were the pioneers in the street railway industry.

In this respect, the coming of electricity as motive power in 1888 was a most important event. At first the cars were small, conforming in design to the lines of the one and two-horse cars which were then in vogue. But the improvement which electricity brought about over the "hay-burners", as the horse cars had become known, so popularized street railway service that larger cars mounted on two four-wheel trucks instead of one were designed, and thus the foundation was laid for many of the designs which are known to the industry today. In some communities, of course, where conditions prevented an increase in travel, the smaller cars were sufficient to meet requirements.

Many improvements were brought forth. Open cars, which had become popular in warm weather, were in many cases superseded by cars with the semi-convertible window system making possible the use of the same car equipment in all-year service, and also eliminating to a large extent boarding and alighting accidents. There was also introduced the prepayment method of fare collection with the adoption of the closed platforms and mechanically-operated doors and steps. All these innovations were introduced in the interests of efficiency; car design keeping pace with the progress of the industry and travel increasing without restraint. But eventually the rapidly increasing number of privately-owned automobiles and the entrance into competition of the gasoline motorbus and the jitneys cut deeply into the street railway's business. The loss was more apparent between the peak periods of the day, when it was almost impossible to even pay the cost of operation, which had so advanced by the increased cost of materials and labor due to the war.

The public did not prefer to ride on the jitneys but "more frequent service" which the electric railways could not furnish with their large heavy equipment decided against the latter. As a solution of the problem it was recognized that a light-weight car was necessary to reduce power costs and that to provide more frequent service a larger number of car units was necessary. The standard safety car was designed in order to effect economies in power consumption and track maintenance, which would permit the operation of a larger number of cars at less expense and by the shorter car intervals give more frequent service to the public. Its lightweight, therefore, of only 16 000 lbs. complete is responsible largely for the operating results obtained. Some contend that the use of double doors to shorten the time of passenger interchange by the simultaneous ingress and egress of passengers is necessary on heavy traffic lines. The experience of many operators has been that the quicker starting and stopping of the safety car offsets the difference in passenger interchange and that in addition the single door of the standard car is essential to one-man operation in that the operator is required to keep his eyes on but one line of passengers at a time and there is less possibility of his missing fares. Also the increase in weight by the use of double doors reduces the operating economies. The standard or "Birney" safety car is undoubtedly the best type for all-day service on any line in any city where car intervals can be shortened and an increase in the number of passengers carried can be obtained.

Where large cars have been operated on as short headways as practicable, either in all-day service or during peak periods only, the Peter Witt car is best suited to meet traffic requirements because of its capacity, and ideal arrangement for the quick handling of passengers. Under these conditions passenger interchange is most important and this type of car with its "pay-as-you-pass" method of fare collection accomplishes this in quicker time than any design of car yet developed. Passengers enter by way of the front platform in two columns and as the conductor is stationed on the forward side of the center doors the entire front half of the car serves as a long loading platform. A most practical seating arrangement is used, with transverse seats in the rear end of the body and longitudinal in the front end. This influences passengers to proceed to the rear end of the car, paying their fares as they pass the conductor, and a better distribution of

the passenger load results. There is no delay in loading passengers, neither is there any at unloading points, it being necessary for the conductor only to collect fares from those who remained in the forward end of the car. The wide center-exit doors also permit passengers to leave in two columns.

It is, therefore, a fact that any street railway company, no matter what volume of business it does, can standardize its rolling stock on Birney safety cars and Peter Witt cars, using the little cars for a given service and the larger Peter Witt cars only where the volume of travel requires large-capacity cars on the shortest possible headway.

Wasting Capital in Bus Competition

EDWIN D. DREYFUS
Engineer,
Pittsburgh, Pa.

ANALOGIES between nature and business are usually most striking. Thus, water passing over a dam without being utilized can never be reclaimed for that purpose and correspondingly it is true in many respects in the case of our capital resources employed in ungainful business pursuits. Our financial and credit agencies report the commercial failures which of course fluctuate with business conditions. The primary causes of failure for a pre-war year were classified by the leading authorities on the subject as follows:—Incompetence and inexperience 15.3 percent, lack of capital 31.6 percent, unwise credits and failure of others 19.9 percent, extravagance and neglect 1.6 percent, competition and specific conditions 21 percent, speculation and fraud 10.6 percent.

Lack of knowledge of the demand for the product, commodity or service and the complete cost of furnishing it are too little understood, and this practically embraces all of these causes, except the last two, of which specific conditions covering sudden price changes and other unforseen developments is predominant. Fortunately in most businesses, the margin of safety is sufficient to permit a relatively wide range of error without precipitating disaster. In other words, the degree of profit in commercial and manufacturing lines must vary widely. With public utilities the case is quite different. It has a turn-over of its investment only once in three to seven years as compared with commercial and manufacturing activities whose turnover of capital commonly takes place several times during the year.

A menacing development to the electric railway during recent years has been the auto bus. In most states, this method of transportation is of a parasitic growth, attacking companies in the most productive business areas only. As a general substitute for the trolley car, the auto bus is impracticable in its present stage of development. There are conditions where it can be used as an auxiliary to the electric trolley, but at present, where regulation does not obtain, it is more prevalent in the form of competition. With the heavy investments required in the railway field, a substantial traffic must be maintained in order that the business may succeed. Auto busses needlessly duplicate the well-established trolley service and thereby create ruinous competition. It is evidently unwise for the travelling public to encourage such economically unsound competition because, eventually, they must bear the inevitable burden by paying higher fares or else obliging themselves to be content with diminished service and accommodations. The average auto bus total operating cost is from 20 to 50 percent more per "seat mile" than that of the electric trolley. Moreover, the convenience, accommodations and regularity of service are distinctly in favor of the well established trolley service. The Des Moines case need only be alluded to in this connection. Undoubtedly their bus experience has been costly to this municipality, directly by slowing down business and indirectly in the loss of commercial prestige.

The psychology of the masses in resenting rate and fare advances during the time of rising costs is one factor which has contributed to the temporary activities of the auto bus. Another factor has been the lack of employment, which has driven many of the laboring class who accumulated a surplus when wages were high to attempt to earn a livelihood in the transportation business. In the case of some of the more prominent and conspicuous bus lines they have been fostered by that class of men who may be properly designated as "financial raiders," who usually promote such schemes and finally unload their stock on the unsuspecting public. In any case, the capital so applied is evidently unwisely employed, and it thus becomes a loss that the people as a whole must bear since the capital involved might have been devoted to more productive undertakings.

A few exceptions, like the Fifth Avenue bus line in New York City, may be cited as examples of where auto busses pay, since a ten cent fare obtains with them, whereas the electric railways in New York are restricted to a five cent fare. But it is also true that an electric trolley system would have been even more profitable in that location and, reduced to the last analysis, the auto bus exists in such places for the reason that it least detracts from and interferes with the purposes and esthetic surroundings on particular thoroughfares.

This whole question is at once very important and particularly serious in numerous instances. The injury to a few will often react unfavorably upon the majority. Collective wealth is increased through productive efforts only—not through destructive influences. Can the people of the country afford to trifle with such wasteful practices which will inevitably become instrumental in diminishing and restricting individual opportunities for a greater development of those facilities that contribute to their material comfort and convenience? This is inconceivable and our efforts

should be redoubled to bring additional light to bear upon this subject in order that a sane and practical transportation policy shall obtain in all localities, either through effective municipal or state regulation.

Encourage Young Engineers to Enter Railway Organizations.

H. H. JOHNSON
Organization Engineer,
Chicago Elevated Railways Co.

THE electric railway industry is still passing through the most critical period in its history. The war period with its rising costs of operation, struggles for increased fares and inability to obtain competent help may have passed, but there is much hard work to be done to restore the industry to a normal basis and build up its financial credit. There has been a tendency on the part of some employees and operators to become discouraged in the future of the industry and to sever their relation with it, even after spending the greater part of their life in it. It has also been difficult to attract the right kind of progressive young men to enter the electric railway field as their life work. They can scarcely be blamed for their hesitancy under the conditions which have existed during the past few years. However, the electric railway has become a part of, and is indispensable to our national life and civilization. There have been individual companies and isolated properties which discontinued operation and there will probably be others in the future, but the electric railways as a whole and as an industry are necessary to the growth and development of the nation.

In order to hasten the recuperation of the credit and standing of the electric railways, it is necessary that everybody connected with the industry from president to platform man and car repairer put forth his utmost effort to win the confidence and respect of the communities in which his company operates. The service rendered the public must be made the most economical and efficient that can be provided. Operating companies must be found to be above reproach when investigated by the various commissions and regulatory bodies. To bring about this condition broad gauged men are required for operation of the electric railway properties. There is a greater need for these men at the present time than ever before.

This is especially an opportune time for the engineer in electric railway service. The conditions just described have clearly demonstrated to the managements the value of the trained engineer. It is absolutely necessary that every detail and every method of operation be analyzed and studied carefully. The trained engineer has proven to be the man best equipped to make these studies and analyses. Accordingly his services are more highly valued by the electric railways today than at any previous time.

The industrial and manufacturing companies have also recognized the value of the engineer and in many cases have attracted young engineers from the electric railway field. The managements of electric railways must see that conditions are made which will attract young engineers into their service. After entering the service they must be trained and developed in such a manner as to maintain their interest. This result will not be accomplished by hiring a young engineer, putting him in some job and then forgetting about him. Some official of the railway company must be designated to look after the young engineers and be held responsible for their education.

Many young men on leaving an engineering school, consider their education completed. This is far from true, as they have received general instruction in a variety of subjects but have not learned any business thoroughly. Their minds have been developed and trained to study and analyze problems as they are presented, but they have had practically no training in the operation of a railroad. The management must recognize these facts and must give their young men the necessary training to make railroad men out of them. They should be given an opportunity to work in the different departments of the road, to get a general idea of the business. During the period of working through the various departments each young man will have the opportunity of determining the branch of the industry in which he is most interested and the management will have the chance to decide whether the young man is fitted for railway work. If he is, he will doubtless show an inclination for a certain branch of the work and should naturally be drawn into one of the departments into which an operating company is divided. If he is eventually assigned to the mechanical or maintenance of way department, he will be more valuable if he has also the transportation department's viewpoint. On the other hand, if he enters the transportation department, his experience in maintaining cars, track and roadbed and in the operation of power houses and substations will make him a more efficient transportation man.

Much of the friction which exists between the different departments would be eliminated if department heads looked at the problem from all sides, instead of having in mind the greatest benefit to their own department. It must be remembered that the road is being run to carry passengers and serve the public economically and efficiently, not for the benefit or record of any one department.

During this period of training and education the young engineer must work as one of the men. He should work as a trainman; as a helper or repairman in the shops; as a laborer or trackman on the tracks, etc. He should work under the same conditions as the regular workman and in fact he must be one of the workmen. He must get their ideas, become familiar with their thoughts, with their manner of living, with

their desires, with their ideas of what the future holds in store for them, with the effect upon them of the issuing of various instructions and orders. He must study humanity. He must be able to see the workingman's side of the case. If, at a later date, he should become a supervisor or foreman, he will find that the handling of men, without friction, is a greater problem and requires closer study and thought than acquiring the engineering knowledge necessary to his position.

Manufacturing companies seem to have had a better appreciation of the value of developing young engineers than the railways. They have solicited their services and established rates of pay which, with the educational features, attracted the young engineers into their plants. Instead of sitting back and making the young engineers force their way into the service, the electric railways must seek out capable young engineers and encourage them to enter their service. The rates of pay must be commensurate with the salaries paid in other industries. The instruction and education of these young men must be placed in the hands of a competent official of the company who will take an interest in them and act in the nature of a personnel officer.

In addition, the electric railways must adopt a general plan of training employes in all departments for better positions and a general plan of promotion. The foreman should be training some helper to take a mechanic's position. If one of the mechanics should quit the helper should be promoted and a new employe started in at the bottom. The general foreman should be training some sub-foreman for the position of a foreman. The master mechanic should know and be gradually training the forman who will be promoted in case the general foreman should become incapacitated. There are various opportunities such as vacation time and absence due to sickness, when the chosen sub-foreman may have a chance to act as foreman and gradually obtain the experience of the higher position.

The young engineer just entering upon his life's work is especially interested in the opportunities for advancement. As a rule, he is willing to do hard work and go through the apprenticeship training if he can see a fair chance for advancement later on. The plan of training and a general plan of promotion, as here briefly described, will show the young man that the opportunity for advancement is always present. Some one in the organization will be promoted when there is a vacancy. Whether he will be the favored one will depend upon his past record and whether he is prepared for the position which is open. Every employe will have something to look forward to. Steady and dependable men will seek to enter an organization of this kind. Young men, both with and without engineering training, will be attracted to it. The officials will have worked up through the ranks after proving their ability through years of service. It will not be necessary to experiment with outsiders in supervisory positions. The organization will be well balanced and fully equipped for any emergency.

The Electric Railway and the Jitney

F. G. BUFFE
General Manager, for the Receivers,
The Kansas City Railway Company

PRIOR to July, 1914, one might have searched in vain through the index of technical magazines for the word "jitney." No such slang expression had ever been allowed to creep into the dignified columns of these journals. From that time on, however, the term jitney takes up perhaps as much space as any other expression. The lowly jitney has taken the time and attention of street railway officials and directors; has intruded into the discussions of financiers; has invaded the courts, local and supreme; has occupied the time of city councillors and public service commissioners; and has intruded into legislative halls. The jitney has been and is today a very troublesome customer and has been the cause of more than one street railway receivership. It is a pest, a pirate, an illegal competitor, and many other things expressed publicly, whereas the things said about it in private would not do to print. Regardless of this, however, the fact remains that in many cities jitneys are daily hauling hundreds of thousands of people and depriving street railways of the revenue necessary for their actual operation. In spite of what street railway people say of the jitney, it is welcomed with open arms by too many of our fellow citizens for our own comfort and wellbeing.

July 1, 1914, the first rattley tin Lizzie appeared on the streets of Los Angeles, bearing the sign, "5 cents." Little did the jehu of this contraption know the furor he was to cause in transportation circles, and doubtless this knowledge would have made little difference. He was out of a job and was the possessor of a second hand automobile. The pavements of Los Angeles were good, the weather salubrious, and people were riding to and fro paying five cents for the privilege. He combined these factors and carried on the first few trips enough passengers to buy a square meal, and the avalanche was loosened. The newspapers heralded his success and that of his fellows in Los Angeles throughout the country, and in large cities everywhere the combination of a jobless man and an old car began to cause trouble for the street railway people. As George Fitch once said, "There was no other way quite as successfully to junk a second hand automobile."

At first the jitney was a fly-by-night affair, but soon the drivers saw the advantages of organization and jitney associations sprang up over night. These voluntary associations laid out routes and schedules, and began to form the nucleus of a skeleton transportation system so that what was at first a mere annoyance assumed the proportions of a serious menace.

The jitney business had a rapid beginning, and almost as rapid an ending at the outset. This ending came about just as soon as the driver of a second hand automobile realized that depreciation was actual as well as theoretical. He discovered that, with his car out of business, his receipts had gone to pay operating and personal expenses and there was no money in the bank with which to continue operations with a new car. So the year 1915 began to see their disappearance, and soon, outside of a few favored localities, the jitney had practically ceased to worry street railway operators. The business depression which was generally responsible for them had passed away, the war in Europe was returning prosperity to our factories, and jobless men were daily becoming scarcer. With wages mounting there was no attraction in leaving an eight hour job for an eighteen hour one driving a jitney at a five cent fare.

As the old saying has it, however, "it is an ill wind that blows no one some good," and out of the first jitney competition came some decided benefits. Street railway operators sensed the possibility of direct competition; some had suffered from it, and everyone was beginning to devise ways and means to meet it. The safety car, which has been such a boon to the industry, was one direct result of the jitney. In many localities and in some states, the early jitney competition had brought about restraining ordinances and laws.

Late in 1917 and early in 1918 new factors and conditions restored the defunct jitney competition to life, and this recurrence is more serious than before. While the plague is somewhat abated in certain localities, in many others it is playing havoc with transportation conditions. With mounting material and labor costs, the five cent fare in 1917 began to be a thing of the past. The street railway companies throughout the United States were rushing to regulatory bodies for fare increases and securing them. These fare increases opened up the opportunity for jitney competition. They worked in favor of the jitney in two directions. In the first place the public in practically every community resented the change from five cents to a higher fare. This feeling was increased by unfavorable newspapers. In many places the public walked to show its disfavor, and as they became available rushed to the jitney. The increased street railway fares made it possible for the jitneys to double their former fare of five cents and, coming at the psychological moment, the public cheerfully came to their support. Economically the jitney was better off under a ten cent fare than under a five cent, and in many localities jitney drivers were able to meet their expenses and accumulate some money.

Strongly intrenched jitney associations sprang up in a number of cities, notably Kansas City, Indianapolis, Newark, Bridgeport, and others. War conditions and war industries made possible the strengthening of this structure. In many cities street railways had all they could do with the facilities at hand, to handle the business, and the jitneys were taking the overflow.

A new element was injected into this competition, namely, the motorbus. Operated on permanent routes, with regular headways, offering a fairly rapid and comfortable ride, these vehicles soon established themselves in public favor. In many cities they were heralded as the forerunners of a system that would supplant the existing street railways. Enterprising gentlemen entered the bus business and from several places propaganda was sent to chambers of commerce, city councils, etc. from those who for a fee offered to put bus transportation in any city. The automobile industry saw a new and highly lucrative field opening, and new bus models began to appear not only in advertisements but upon the streets. The situation soon became and is today extremely serious in many localities.

However, like the rise and fall of the first jitney epidemic, indications are that this recurrence is on the downward part of the curve, and that it too will pass away. An educated public opinion and several very expensive examples, expensive both for the companies involved and for the communities, have helped in this developement. Those visionaries who a few months ago were hailing the advent of the bus as the death knell of electric traction are becoming fewer since Bridgeport, Toledo, and Des Moines have furnished sign posts so those who run may read.

There has not yet been offered any argument that can effectually prove that, for mass transportation in our large centers, anything will in the next fifty years supplant the modern electric street railway. Furthermore, it is rapidly becoming recognized by the public generally that adequate, reliable, efficient street railway service cannot be furnished if competition is to be permitted; that no community can support two independent systems of transportation, the one upon which the public relies being burdened by charges such as paving, and so on. The public is also realizing that adequate street railway transportation means an investment in facilities sufficient to cover the entire city and to transport its population at any and all times. It realizes that this investment cannot be maintained and continued if unrestrained competition is to be permitted to take the revenues necessary to maintain and continue this investment. The public is also recognizing the fact that to provide a de luxe automobile service for a comparatively small number, the large majority who depend upon the street railways are being penalized by higher fares and inadequate service. The public furthermore recognizes that, if the entire town is to be served the outlying districts and the long hauls, then competition must not be permitted to cover the heart of the traffic possibilities with short hauls, taking the cream of the business from the company upon whom falls the legal obligation to render a complete transportation service.

There never has, of course, been competition in the strict sense of the word, because competition implies "a fair field and no favors," and this cannot be said as between the jitneys and street railway service. The jitney is unrestrained, heart-whole and fancy free. It can select the street it desires; can furnish service only to thickly settled districts; is under no obligations to serve any particular section; is not called upon to pay for the pavement it destroys nor is it subject to any of the other charges and obligations imposed upon the street railways.

Education, and following education, proper regulatory laws and ordinances, are the weapons which are putting the jitney and unrestrained bus competition out of the picture, and will continue to do so. The people are waking up to the dangers involved; property owners see the hand-writing on the wall if street railway systems are allowed to be permanently injured, and as a result city councils everywhere are solving the problem by ruling out the jitney.

In Kansas City very recently two ordinances have been passed which have effectually served their purpose. The first prevents the jitney and motorbus from operating on streets now served by the street railway system. The second requires jitneys to secure the consent of fifty-one per cent of the property owners on any route upon which they attempt to operate. As a result of this there are no jitneys operating legally in Kansas City today. At this writing, about one hundred and thirty of them are half-heartedly attempting to evade the law by accepting tips and advertising free rides. They die hard, but nevertheless they are dying.

In Des Moines, although public opinion and a large part of the press was incensed at the street railway and was extremely unfavorable yet, upon suspension of street railway service, the public and the city council refused to grant a five year franchise to motorbus companies. Such motorbus transportation as the city has is a failure as far as moving the people comfortably and efficiently is concerned. This fact is recognized in Des Moines. The people there are almost a unit in admitting that the transportation business of the city cannot adequately be furnished by the motorbus. As a result of this, grudgingly though it may be, some favorable franchise will be granted to the traction interests.

Now the trend of discussion seems to be along the line that street railways should avail themselves of the motorbus as an auxiliary and subsidiary form of transportation. Motor companies are pushing this propaganda, and while it may be necessary and advantageous in certain localities, yet this is a field in which haste had better be made slowly. There is a danger in the industry as a whole of pushing the bus propaganda too vigorously. There is every danger of demands being made upon us which we are unable to meet. If a few busses are placed in one section of any city to serve as feeders to an established line, there is every likelihood that immediate demands will come from other sections, with the result that we will be attempting to supply almost a taxicab service.

Many of our cities are today over-tracked rather than under-tracked, and further expense, even if in the nature of trackless trolleys or motorbusses, may be the means of furnishing service at an expense which would not be justified by the revenue derived.

There is every indication that our cities are now awake to the dangers of this competition. As between a good, efficient car system and a combination of cars and competing busses, neither adequate, they will choose the former. The public, knowing that the preservation of adequate street railway service is absolutely essential, will not permit competition to ruin it. All signs point to a lessening of this evil and very soon the second chapter on jitney competition in the American street railway industry will probably be concluded.

An Appeal to Manufacturers and Dealers

BARRON G. COLLIER
Chairman, Committee of Publicity,
American Electric Railway Association

As an advertising man I believe that the outlook from the manufacturers' and dealers' standpoint should be more encouraging than it has been in several years. A very large part of the advertising and publicity work done in behalf of the industry surely will redound to the direct benefit of the sellers of electric railway supplies.

One point that has been driven home strongly by the advertising section of the American Electric Railway Association, is that fair treatment of electric railways is essential to extensions and betterments on the lines. Naturally, the public, reacting to this appeal for a square deal for electric railways, will want betterments and extensions, and when they come the maker of and dealer in supplies will be the direct beneficiary. Thousands of pieces of literature and hundreds of columns of newspapers articles dealing with the need of money for betterments and extensions have reached the public in the last year. More of it is coming.

Manufacturers and dealers can do much to help the industry by seeing that their employes and others with whom they come in contact receive and read this material. Many channels are available for its distribution which have never been used. The public will learn the truth about the electric railway only so rapidly as the truth is put before it and, in turn, buying of materials and supplies will pick up in exact ratio to the speed with which the public becomes cognizant of the truth and extends fair treatment to the roads.

May we earnestly urge your help and co-operation in helping us to disseminate this thought—distribute through every means within your reach advertising matter which will co-ordinate what we are doing so that the united purpose of our messages will bring about more speedily the rehabiliation of the industry.

Electric Railway and Welfare Work

JOSEPH H. ALEXANDER
Vice-President,
Cleveland Railway Company

NO discussion of welfare work, whether applied to industry in general or to street railways in particular, can hope to receive much consideration today unless somewhere in it we can affirmatively answer the question—"Does it Pay."

Long ago I have been convinced that our labor must be purchased and maintained much as our material and equipment is. It has got to be right and reasonably near the correct specifications in the first place, and, thereafter, it will respond to care and to reasonable attention with longer life, and better service during the period of its use. By longer life I mean a smaller turnover.

I want particularly to bring out the thought, however, that, notwithstanding I am a believer in welfare work and social betterment of our employes, it is my opinion that no effort of this kind will bring the maximum of good results unless, under the plan of introduction, the employes themselves do a portion of the work and, to some extent at least, initiate it or carry it on. No worthwhile employe relishes a good thing that is thrust upon him so much as he does one that he helps obtain for himself. No one of us likes to feel we are being patronized. Good labor relations will not thrive under a care that amounts to coddling. The employes must have sufficient interest to push the work themselves because they recognize its value to themselves or it will prove to be worthless as welfare work.

> IT is no more difficult to promote welfare work on a street railway system than in any other industry.
>
> Labor, somewhat like material and equipment, will respond to care and reasonable attention with longer life and better service.
>
> Welfare work which encourages employes to help themselves will pay.

Furthermore, our welfare work should stand mostly for operating perfection, and must be confined more or less to the place of employment, and, to a large extent, the hours of employment. The employes should be free to live as they please outside.

With those restrictions it has been our experience, and I think the experience of every one who has undertaken welfare work, that a management which year after year proves its sincere good-will towards the employes obtains a valuable return, figurable in money, by reason of a decreased labor turnover; and reaps a large harvest of satisfaction out of the additional loyalty of its employes, and from the recognized benefits inevitably accruing to the community.

It is no more difficult to promote welfare work on a street railway system that in any other industry. An important expenditure of money is not required, and a business policy which appreciates the value of encouragement and expressed good will, and the many good things which cannot be purchased with money, may expect to meet in return a policy on the part of its employes calling for more than mere perfunctory service and one that carries with it a loyalty and good will that increases year by year. Without these things, an employe is, of course, of little real value.

PLANS FOR CO-OPERATION WITH THE EMPLOYES IN BETTERING OPERATING CONDITIONS

No matter what our viewpoint is, it is my opinion that there has never been a time so ripe as this for well directed welfare work along the line of bettering operating conditions. It is next to impossible for us to look at the matter from any viewpoint other than as dealers in transportation because that is the thing we are in business to sell. One of the most important requirements for the merchandising of transportation to the best advantage is the rendering of an excellent and courteous service to the riding public. So far, therefore, as our relations with the riding public are concerned, we cannot go far wrong by seizing every opportunity to better our operating conditions to the end of good service. And furthermore, I think that just at this time, and for the next few years to come, efforts of this kind will receive a more obvious welcome from the car riding public and produce more outstanding and favorable and immediate results than ever before, because the peak of criticism against the street railway industry of the country, which came as a result of the necessity for universally increasing fares, has been passed and the public is rapidly evincing a more friendly attitude than ever before.

So far as our relations with our employes are concerned these two features are of outstanding importance:

> The closer we can draw to us the lasting friendship and loyalty of our employes and cooperate with them in bettering our operating and their working conditions, the sooner and more readily will they respond to our teachings and our policies and render the riding public the courteous and intelligent service we are striving to provide.
>
> The more we can arouse and stimulate on the part

of our employes a healthy interest in the company's welfare and an appreciation of their own part in it and a reasonable contentment and pride and concern in and for their work, and their cars, and their passengers, the more assuredly will they, little by little, bend their efforts towards the new and better labor relation fostered by local organizations and based on local conditions and looking towards their own mutual welfare.

With the exception of a short time, about ten years ago, when this company was undergoing reorganization, we have for a period of over fifteen years endeavored to gain the co-operation and the confidence of our platform men through rules providing for the hearing of grievances and suggestions on the part of the men. The first agreement provided that a committee consisting of the officials of their local organization should present to the Superintendent at a regular meeting, the time of which was fixed, any individual or other grievances relative to discipline or service and, in case of any dissatisfaction as a result of the hearings, were given the right of appeal to the General Manager, and a further right of appeal to the President, in case they were still dissatisfied. That committee meeting, which was first inaugurated with only the matter of discipline in mind, has been developed to a large extent and has proved to be an avenue to an unexpected and valuable co-operation between the management and the platform men. Under the original arrangement the grievances and demands for appeals were so numerous and cases were so consistently appealed to the President that the intermediate appeal to the General Manager was discontinued and, under the present arrangement, when the platform men feel that a rearrangement of runs or schedules is advisable in order to make their work easier or their pay more uniform, or whenever any one of them feels he has been unduly punished or censured or improperly dismissed, or, in fact, has any grievance at all which the Transportation Department has not dealt with to their entire satisfaction, the matter may be brought directly to the President at a regular meeting consisting of the President, the representatives of the man, the man aggrieved and any of his fellow workers or other company employes who may be concerned in the particular matter in hand, or whose presence may be needed properly to dispose of the matter. The rules are made by agreement between the men and the company, so that when they are infringed upon there is a minimum of censure for the company if he is penalized. There have been occasions when some schedule changes have been desired by the men and although generally when given the task of working out these changes they have discovered their requests to be not feasible, yet, last year, as a result of their requests, some changes were made which proved to be beneficial to them and in no way harmful to the company. I am quite positive that these committee meetings have gone a long ways to make our relations with our platform men agreeable and harmonious, and I believe that to our efforts to fully meet their requests and, so far as we can ascertain them, their needs from time to time, may be attributed our successfully avoiding two serious labor difficulties in the last two years. The company is very strict and very firm in requiring that rules be obeyed, but endeavors in every way to give consideration to the suggestions and requests or the grievances of the employes.

FIG. 1—STANDARD OPERATING STATION OF THE CLEVELAND RAILWAY COMPANY

In our shops we have never had a similar means of communicating with our men but we have been unusually fortunate in having both as our Master Mechanic and as our foremen men who have grown up in the employ of the company, and who hold their present positions through promotion, and there is an unusual close bond of friendship and obviously a strong spirit of contentment among the men employed there, which is entirely the result of the fact that they feel at liberty, at any time, to discuss as friends the matter

of conditions or pay or promotion, or their own personal welfare, as the case may be. The officials of the company invariably endeavor to respond favorably to as many of these matters as eventually come to their notice.

In other words, I believe we have learned that the spirit of friendship for and among our employes is worth far more than any entertainment we might provide, or any gifts or expenditures we might make in

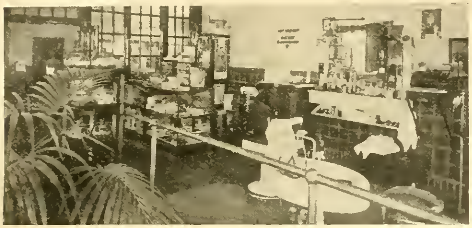

FIG. 2—EMPLOYES' BARBER SHOP, CONFECTIONERY AND LIGHT LUNCH ROOM

their behalf without requiring any effort on their part. No employe feels the sting of patronage when we deal with him as a friend. The worthwhile employe resents the thoughts that he must be looked after as a child. He must be allowed to help himself. We are very cautious in this respect and endeavor to make self-help and pride and self-respect and co-operation the controlling features of anything in the nature of welfare work which this company encourages.

CLEANLINESS, SANITATION, COMFORT AND PRIDE

I hardly believe it is possible for any one of our employes to walk into one of our standard operating stations, or into our shops without feeling some pride in the fact that he is a part of the organization which maintains them. We have tried to make our operating stations look as well architecturally as is compatible with appropriate cost and service and inside we have attempted to provide every modern improvement and convenience.

Our shops and main storage yard cover an area of approximately thirty-eight acres, and before the machinery was installed every piece was located on the drawings and consideration given to every comfort and convenience of the men. The working areas are light, airy and so arranged that orderliness is obtained almost as a matter of course. The unusual cleanliness and orderliness of our shops has been the cause of frequent comment on the part of visitors and it is almost entirely due to the thought and care which was given to the location of machinery and the room which men need to do their work properly and comfortably. First aid surgeries, lunch room, lockers and showers are provided and there is no reason why an employe should leave for home looking other than neat and clean and refreshed after his days work.

We have recognized the necessity for men spending some time in our operating stations at various hours of the day and night just before and just after shifts in runs, and for emergency occasions, we have provided sleeping accommodations which they may use. The sleeping rooms are approximately thirty by forty-two feet in size and steel spring cots are used. These rooms and the bedding are kept clean and neat and ready for inspection at any hour of the day or night. A portion of the cots are provided only with mattresses and blankets and pillow, while others are provided with white sheets in addition. Those men who wish only to rest for a short period and who do not remove their shoes or outer clothing use the cots which are provided only with the blankets, but always we insist on the utmost cleanliness and care to keep the rooms wholesome and fit for occupancy.

Space is furnished in which the men may place pool tables which they have purchased through their club organization,—an organization which we encourage in every respect, and they have in every case taken advantage of this and seldom do you find the tables unoccupied. For their convenience space is also given over to a barber shop and confectionery and light lunch counter, and the prices charged at these places are kept under close supervision.

We are very proud of the type of men to be found on our street cars and in our shops, and of the manner in which almost invariably we find them endeavoring to live up to the spirit of our instructions. We have some employes who have been with us for a period of from twenty to thirty years, and a much larger number for ten years or more. These facts have a direct bearing on our expenses in several ways: for instance, we find our percentage of accidents much higher among new men than among old employes. To take a concrete example, during the last two years we have averaged nine accidents per man per year in our first year group of platform men, and an average of four accidents per man per year in the group of

FIG. 3—POOL ROOM FURNISHED AND MAINTAINED BY EMPLOYES' CLUB ORGANIZATION

platform men who have been employed ten years or more. From the standpoint of claims made alone, and ignoring entirely the matter of repairs to our own equipment and loss of time for both men and equipment, our accidents have averaged in the neighborhood of $50 each. That would amount to $450 per man per year if we had a 100 percent labor turnover each year

and but $200 a year if all our employes had been with us for over ten years. In other words, on the basis of 3000 platform men, it would cost us $1 350 000 a year if we continually had new men on the job and we could apparently reduce this to $600 000 and thus save $750 000 a year if all our employes were ten year men.

These figures give one concrete example of a saving which can be directly traced and attributed to the platform man's satisfaction with his job. It can be traced directly to our efforts to bring about that condition of affairs. Whenever we have given a man a car he is proud to operate and ride upon; and an operating station that compares favorably with any building in the neighborhood; and when we have seen to it that he and all his fellows are dressed in a manner which enhances that pride in his work; and as often as we have brought home to him the fact that he is our one point of contact with the car riding public and that it is upon him we must depend for the good will of the public towards us and him; at those times we have been directly contributing to his contentment and satisfaction with his work and, in direct proportion, to our own bank account.

FIG. 4—FIRST AID SURGERY

Those figures, of course, relate solely to one element of direct loss from labor turnover and ignore even the cost of schooling a new man and the intangible annoyances which every new man causes when he is being trained in the early stages of his employment. They are cited simply to prove that we can find some tangible ways in which wise welfare work will pay.

A FUTURE WHICH AN EMPLOYE CAN VISUALIZE

It is difficult for many of us to appreciate how different our viewpoint is from that of the men who are employed by us as mechanics and on our cars. We have grown to look upon provisions for our future, such as insurance and investments, as a matter of course. Some of us are even wise enough to give some consideration to the manner in which we eat and live. Many of our employes have neither the wisdom nor the provident inclinations properly or effectively to take care of these things even though they appreciate the value and necessity for doing so. And yet our employes, and particularly our older and more stable and contented employes, are such an asset to us that we cannot afford to allow them to ignore their health, their future, nor their family's welfare after they are gone.

HEALTH INSURANCE—SUPERANNUATION

Mr. E. J. Doran, Traffic Manager for the New South Wales Government Tramways, aroused a considerable amount of my interest when he visited our property some months ago and among other things explained their method of providing a form of insurance or retiring fund for their employes. Their idea is, of course, not a new one, but was so effective and from his account of its workings so satisfactory to everyone concerned that I obtained a copy of the New South Wales law making these provisions and found it very interesting. Under their plan a deduction of 1.5 percent of their salaries is made from time to time and the fund thus created, together with a like amount contributed by the Railway, is placed to the credit of a special account in the government treasury and called the Government Railways Superannuation Account. A man who is over sixty and has retired after ten years or more of service or, who is under sixty and has, after ten years of service, been compelled to discontinue work through infirmity or for any other reason, is entitled to a superannuation allowance which is payable every year for the rest of his life. The allowance amounts to one-sixtieth of an average taken of his earnings during his term of service multiplied by the number of years of his service.

There are similar methods in use in our own country and it is my opinion that such a provision is not complete without offering him an opportunity for obtaining a reasonable amount of inexpensive insurance.

It would surprise a great many to know how many of their employes who are apparently well and healthy are really far below par. Fifty percent is a low estimate. You will recall that thirty-three percent of the young men—men between twenty-one and thirty-one—were rejected for the army. I have never yet discovered a way which seems satisfactory to me for helping a man maintain his health up to a point reasonably near a proper standard. We all seem to resent an outside supervision or effort to tell us we should not eat this or that food, or indulge in this or that form of work or recreation. Yet health is the greatest asset which our employes have and our employes in turn can be made the greatest asset we possess. I have recently given some study to a plan along this line which comes nearer the result desired than anything I have yet found. The reason this plan seems to meet the need best is that it attempts to interest the employe himself in his health and the plan is offered to him in the nature of an opportunity and not forced upon him. The plan seems to be founded on the realization that the employe must pay part of the expense in order to appreciate the value of the service received. If a person pays for something he naturally wants to get some-

thing for his money. The only way he can get anything is by following out the suggestions made by the doctor. Under this plan a man who pays twenty-five cents a week or thirteen dollars a year, with his employer paying a like amount, can obtain $1000 life insurance, $10 a week health and accident insurance, and a health supervision and service of real value. By paying slightly more, those employes who desire can obtain more insurance and larger weekly health and accident payments. The plan thus offers an opportunity not only to provide against accident and death, but to guard against the development of disease and upbuild the vitality and improve the general physical condition. I do not think that a plan has yet been devised which will actually succeed in making men take proper care of themselves. But any plan which does not give the employe something for nothing and which makes them pay a reasonable price for it and tends to educate them to the need for it and encourages them and helps them to acquire it without it being burdensome to them, comes very near to being an ideal plan for maintaining at the highest possible standard this asset which is too valuable for us to be entirely ignored.

HOME BUILDING FUNDS OR CREDITS

Some months ago, when the matter of inadequate housing was viewed as a serious matter in almost every city in the United States, the City Council of Cleveland passed a resolution to the effect that the Cleveland Railway Company should be permitted to lay aside a fund from which loans might be made to employes for the building of homes under certain reasonable restrictions. The general financial situation made it impossible for us to accept this suggestion on the part of the City Council, but the fact remains that every property of sufficient size to enable it to handle a fund and manage a series of loan accounts of this kind would be doing more for their employes and for themselves and for the community than many realize. A good citizen is a good employe to have in your organization. A man who owns or is acquiring his own home makes a better citizen and a more stable and steady and valuable employe. I do not know when our own management will feel in a position to recommend a plan of this kind, but it is a thing which we should keep in mind and which every business organization and large employer should carefully investigate, always bearing in mind the fundamental requirements in this, as in every other bit of help or welfare work that is offered:—the employe must be merely offered the opportunity to do something himself. We must appreciate that we do more harm than good when we tell our employes we are going to give them something. Although some may appreciate what we are doing, the majority are most likely not to do so.

I am convinced that where welfare work consists of co-operation with our employes in lieu of help, and where friendship is obviously the basis on which that co-operation is offered, welfare work does pay. It pays from the standpoint of money saved; from the employes' higher standard of self-respect and better physical condition. And futhermore, our own feeling of pride in our employes, and in the work we are doing for the community, will in themselves prove of sufficient value to make that sort of welfare work worth our while.

The Problem of Street Congestion

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STREET congestion brings out more forcibly than any other urban problem the greatest strength and, at the same time, the greatest weakness of electric railway service. Its strength is shown by the superiority of electric railway facilities in economy and capacity for carrying large numbers of people over long urban distances. There is no other form of transportation which can supply the demand for urban transportation at a price within the ability of the general traffic to bear, and the basis of this cheapness is the tendency of large numbers of people to travel at the same time. Almost any other form of transportation—automobile, auto-bus, horse-drawn vehicle or walking—would be more economical for individual movements from place to place, on account of the expensive investment necessary to provide electric railway service.

Unfortunately this fundamental basis for our industry carries with it the compensating weakness of impairment in quality of service. In many communities, a condition of congestion has been reached where, in the minds of the car riders, the value of the service is below the small charge for it.

There are two avenues of attacking this problem; one is to convince the car riders that the service is worth the price, the other to reduce the avoidable congestion, both in the cars and on the streets, in order to counteract so far as possible the impairment to service. Neither of these methods is independent of the other. In order to convince the public that the price is right, they must first be convinced that the management is doing everything in its power to improve service; and many changes in service will be impossible unless the public feels that the price is right.

This brings out the principal factor in the problem,—the relation between the railway management and the public. With reasonably good relations, necessary changes in operating methods, routes, track and

equipment productive of improvement will be comparatively easy.

The importance of this problem indicates the fact that its solution involves nearly every angle of railway management.

1—As noted above, public relations will determine largely the success or failure of efforts to make necessary changes.

2—A strong financial position will make possible expensive changes in track, equipment and operating methods.

3—Good operating methods must follow good public relations and a strong financial position, if these are to be maintained and improved.

Mention of a few of the details which enter into the solution of this problem may be of some help in understanding its scope and complexity. There is no single change or method through which radical beneficial results may be secured. Nearly all of the principal influences in this problem are interrelated in such a way as to require a broad consideration of many in connection with even minor changes.

The first idea which naturally suggests itself is the reduction of interference by other vehicular traffic with street car operation. Suggestions along this line range all the way from double-decked streets and subways to effective control of traffic under present conditions. It may be that a second-story street for light vehicles and pedestrians in the over-congested districts is a solution of our problem; this is not clear at present. Double-decked streets and bridges are not unknown, so that the proponents of this idea have some basis for their opinion. Surface car subways and elevated tracks, taking surface cars out of street congestion, have afforded some relief. The difficulty in this method is to distribute the burden of expense properly over the other beneficiaries of such facilities. Usually the car rider cannot carry the burden alone.

Less directly but just as effectively, rapid transit subways or elevated lines will lift from the surface system sufficient passenger traffic to bring relief. A rapid transit elevated or subway system which may be used as a trunk line into which surface cars transfer their traffic after a short haul, would produce good results for a number of our large cities. The problem here is to relieve the car rider from carrying the entire burden of expense and to place a part of the burden on other beneficiaries of such a facility. It is conceivable that the over-congestion problem will become so acute as to force public co-operation in the construction of facilities which will transfer the passenger traffic in the over-congested districts from the streets to a subway or railway system.

There are intersections of streets where the separation of the grades of the two intersecting streets could be made. However, such cases are comparatively rare and would not allow cars or vehicles to turn from one street to the other, unless one street were exceptionally wide.

Broad developments of city plans for the establishment of through vehicular routes, and by-passes around the business district, so located and arranged as to attract traffic from the over-congested streets and railways, promise some relief. In a great many cities the bad condition of the paving in trackless streets, coupled with the good path offered by the rails for heavy truck traffic, brings about an unbalanced condition of traffic with too much on the railway streets, too little on the trackless streets and additional interference on the streets used as detours from the bad paving to the tracks and back again.

Narrow streets form probably the worst cause of street congestion. Where the street car traffic is light enough to permit the cars on these streets to be operated over one track in the same direction, one-way direction for traffic will relieve congestion. Where street car traffic requires more cars than the capacity of a single track, one-way operation will increase street car congestion. Aside from one-way operation, about the only method of increasing the capacity of narrow streets is to widen them. The suggestion has been made to convert the entire sidewalks of such streets into vehicular roadways, and provide sidewalks by means of arcades under the second floors of the abutting property. This proposition is not so visionary as some other ideas which have been seriously advocated and in many instances it would provide considerable relief at less cost than a complete program of widening. Coupled with this suggestion is one to provide arcades through the middle parts of downtown blocks from one street to the other. We have practical examples of this kind of facility, which relieve the sidewalks of some of their pedestrian traffic.

A considerable feature of traffic congestion at street corners is the pedestrian traffic. Perfect control involves delays to pedestrians waiting for traffic signals. To provide for a serious condition of this kind, subways similar to those used by the railroads to permit passengers to pass from one station under the tracks to another station might be used to advantage. A subway of this kind under an entire street intersection could provide for the free flow of pedestrian traffic in all directions, without interference to street traffic.

The full capacity of present streets is not used now, either on account of legal obstacles, poor traffic regulations or failure to enforce regulations. Public opinion still insists that property owners have the right of practically unrestricted ingress and egress, regardless of others dependent upon the free flow of traffic in the streets for their well being. The extension of the police power in New York to prevent the eviction of tenants and in Kansas to prevent stoppage of industrial operations would seem to indicate that some day vehicles will be prevented from interfering to such an unreasonable extent as they do now with the comfort and convenience of thousands of people for the benefit of a very few. When the public thoroughly under-

stands this feature of the interference, the congestion in street traffic caused by unnecessary stoppage of vehicles will end. The fact that some inadequate ordinances have been passed to prevent parking and even the operation of vehicles at certain locations and at certain times indicates that the public is beginning to realize the justice of the car riders' complaint.

The strict enforcement of adequate ordinances would go a long way toward increasing the present capacity of our streets. The size of motor vehicles which may be operated, through the congested district at least, should be limited so as to prevent undue interference with traffic. The presence of horse drawn vehicles in over-congested areas is the worst example of sacrificing the welfare of many to the narrow interest of a few. Nothing can do more to make ineffective the efforts of those engaged in trying to move traffic promptly. Delivery vehicles unloading while on tracks, and obstructions on the sidewalk forcing pedestrians into the streets, should not be permitted.

A free flow of all other traffic in the congested streets of our cities, however, will not satisfy the car rider. There are other factors in the problem which, in many cities, would bring about over-congestion of car traffic, even if all other vehicles were excluded from the streets. The first limiting feature would be interference of cars with each other.

The capacity of tracks for loading, unloading and transporting passengers is limited. The maximum number of cars, including a proportion of two and three car trains, that can be dispatched regularly over a single track with heavy loading is less than two-hundred cars per hour even in a subway free from interference by other vehicular and pedestrian traffic. The number of cars which can be dispatched over a city street will depend upon the traffic conditions and a number of other factors mentioned below. Under the most favorable conditions, which do not include the concentrated loading at one point found in subway stations, somewhat less than one-hundred and seventy-five cars per hour can be operated. A successful schedule under the most favorable conditions of one-hundred and fifty cars per hour may be expected. From this figure the possible effective schedule drops rapidly with the adverse street conditions. The actual maximum scheduled capacity of any single track can be determined only by experience and observation.

The point is that, with heavily congested traffic, all of the reasonable changes in the use of streets to allow more effective operation of street cars will not solve the problem of street car congestion. Aside from congestion due to other causes, the congestion from street car operation alone demands radical changes in methods. In many cases surface car subways, even liberally assisted by general taxation, cannot solve the problem. An adequate system of this kind, on account of its enormous expense and limited capacity as compared with a large capacity, high-speed system, would be at best a poor makeshift.

The establishment of business centers remote from the central business area has undoubtedly provided some relief from central congestion. This tendency toward decentralization, brought about largely by congestion in the center, brings about a demand for rapid transit which will in turn accelerate the distribution of business activities over a wider area. Office buildings miles apart, located near rapid transit stations, are closer in time than those not so served, which are only a few blocks apart. Ideal urban passenger carrying facilities would include a high-speed, large-capacity system along the axes of traffic in the industrial, commercial and residential districts, with surface car radials connecting with and feeding the large capacity system.

In addition to the general situation, there are a number of features in the actual conditions which should be studied in each particular case. The first essential is service. Routing should be such as to provide the desired transportation with the greatest dispatch and least discomfort for the car rider. Transfer of passengers should be avoided if possible, but where transfers will provide generally more attractive service than through operation, changes in routes requiring transfers should be adopted.

Many systems are over-congested on account of the locations of routes. Routes from different sections cross and recross other routes and other traffic throughout the over-congested districts. The history of such routing makes any rearrangement particularly difficult. In many cases traffic has developed largely on account of the location, and any change in such routes brings forcible antagonism. Owners of large stores who believe that their prosperity depends upon the business brought to their doors by present routes may be expected to exert their influence against any change. The argument that a general improvement in car service will benefit them more than the maintenance of their special ineffective service does not carry much more weight to them than an appeal to the average man to sacrifice what he considers his own welfare to the general good. Public opinion, however, has in the past forced changes in routing for the general benefit of the community and of the car rider, so that we may be hopeful for such changes in the future. They may not be all that they should be but, properly directed, will produce some benefit.

A usual suggestion for the relief of congestion is to route lines through the over-congested district from one outlying section to another. The usual objection of unbalanced traffic on the outer ends is not strongly supported by those cities which have used this method. As a general proposition, the surplus service on one end has stimulated traffic to such an extent as to bring about a fair balance, so that excess mileage or deficient service on one end or the other has been reduced to a minimum. The most forcible objection to through routing is the limited traffic capacity of streets in the over-congested area. In many cases through routing

might benefit the present situation temporarily, but it seems a temporary make-shift, and will establish currents of passenger traffic which will be hard to divert or transfer when the over-congestion in the central district prevents successful through operation. This time, in most large cities, is not far off and it will be more difficult to re-route through lines out of congestion than to move back lines looping back in the congested district. Through routing also involves possible complications in fare collection systems on some systems, causing congestion which would counteract any improvement that might be made.

Assuming that through routing is generally not a wise expedient for the relief of over-congestion, the best method, aside from radical measures such as subways or elevated systems, seems to be to route cars so as to reduce congestion to the least point, consistent with the best quality service to the car rider. In many cities, car service for comparatively long distances has become slower than a walk, with frequent blockades. The car rider must choose between slow irregular expensive service direct from origin to destination and faster service to and from the edge of the over-congested district. To supplement this service, continuation transfer service on short cross-district connecting lines through the over-congested streets must be established. The inconvenience of transferring or walking will mean no more than at present for a large number of car riders. The balance of the traffic can be handled more effectively through the over-congested district on a smaller number of cars routed through, avoiding the interference to traffic due to turn backs and to the excess cars not justified by the traffic.

Unnecessarily extensive changes along this line are inadvisable. Wherever street conditions can be produced which will allow cars to run through from the origin to the destination of their passengers, no change should be made; but where the general effectiveness of the service and proper economy in operation require changes in routes, that the general policy of turning lines short of the over-congested district with short connecting lines through that district will bring the best results. No fixed policy to determine the proper action in every case can be laid down. Some conditions, notably over-concentration of loading, would make such procedure inadvisable.

The principal symptom of the disease of over-congestion is slow operation with its resultant excessive costs and irritation to the public. A sure cure would be to eliminate all street car traffic, just as the amputation of the head would surely cure a stomach ache; but the net result would be business death. First, investigate the causes of over-congestion and then apply such remedies as promise to improve general conditions without impairing the general usefulness of our railways. Mistakes will undoubtedly be made, but a certain number of mistakes are inseparable from human activities and must be expected in any big effort for improvement. Co-operation and well intentioned criticism are needed to reduce mistakes to a minimum and secure real progress by positive action. Avoid futile experimental changes, which cause irritation to passengers.

One of the most attractive means of reducing over-congestion is what may be called staggering the hours of opening and closing stores and offices in order better to distribute the traffic. The advantage to the car rider is obvious, but the difficulty of securing co-ordinated action by the various interests involved has prevented a very general use of this plan. Every effort should be made to reduce the peak demand for service and to spread the traffic over the off-peak periods when a large part of the system capacity is idle. These results might be secured by making the service more attractive through reductions in fare, extension of routes or otherwise during off-peak hours.

The fare collection system may be adapted to conditions so as greatly to relieve congestion. The pay-leave outbound and pay-enter inbound system on cars which are looped back at the central district appears to be an important help in getting cars over the road promptly. This method has been abandoned in some instances for special reasons. The system which requires the passenger to pay his fare as he passes the conductor who is stationed near the center of the car has many advocates; for through operation and in cases of crowds at locations out of the ordinary every-day experience, it yields better results.

Card passes which entitle the holder to an unlimited number of rides help to facilitate fare collection, as does the liberal use of tickets or tokens. This liberal use of tickets is augmented by a considerable difference between the cash fare required and the price of the ticket. Street men to assist in collecting prepaid fares and others to facilitate the loading of cars at heavy traffic points help to accelerate traffic.

The size of cars which is limited in some cities has a serious effect upon congestion. Broad streets permit large cars with liberal entrances and exits. Narrow streets require small cars and limited openings, which increase the time of loading and unloading, and decrease the ability to move passengers promptly, thereby increasing street congestion.

The low-floor car has been of undoubted benefit in accelerating traffic. Cross seats, hand-holds and railings work both ways; in light traffic they help passengers to move promptly, but when the car is crowded, act as obstructions and retard the flow of passengers in and out of the car. Cross seats, however, are demanded by car riders, and must be supplied.

The use of the same route in the congested district by cars serving the same general outlying section not only provides more regular and frequent service for some patrons, but, through a more even distribution of traffic, reduces unit overloading and consequent delays.

Loading facilities, such as loading platforms and

safety zones which permit passengers to board and leave cars promptly in safety and eliminate the necessity for damming up vehicular traffic to the rear of the car, have produced good results.

The location of stopping points for cars justifies the most careful consideration. Too many stops means trouble in adherence to schedules. The running time allowed is either too little when all stops or too liberal when few stops are made, causing bunching of cars in the former and dragging in the latter case; both of which cause congestion. The location of stops with reference to their influence on traffic in general has an important bearing. For example; at branch-offs, branch line cars should stop for passengers on the branch and not on the main line. In the same way, stops can be changed so as to relieve vehicular traffic by locating stops beyond the path of heavy diverging traffic. In practice, stops in the middle of blocks leaving cars free to proceed at the intersections, have given good results. Over-concentration of loading and unattractive service through long distances between stops should be avoided.

One matter which does not seem to have received the consideration it deserves is the exact designation of stopping points and the positive stopping of cars at those points, in order that passengers may not lose time walking from a stop sign to the actual stopping point. Different types of cars with entrances located at different places should be avoided, because they tend to confuse passengers and add to delays.

Multiple berthing is of considerable assistance in expediting traffic, particularly with street men in attendance. The full value of this system is shown in some surface car subway stations, where the route of each car and its berth location are shown before arrival, on an indicator visible from all parts of the station.

Types of cars present interesting possibilities. Over-congestion is directly affected by the amount of street area occupied by transportation facilities. Other things being equal, congestion can be minimized by using a car which occupies the least amount of street area for the number of passengers carried. The question of double-deck cars naturally presents itself. Here is a unit which occupies the same street area and will seat twice as many passengers as the single-deck car. During rush hours, as a transportation unit, it may not be considered as having double the capacity of a single-deck car, but it does have a substantially greater capacity than the single-deck unit. The increased track capacity and street relief in the congested district, and economy in man power, offers attractive rewards for the development of a double-deck car which can load, unload, accelerate and generally maintain schedules as well as the single-deck car with a reasonable degree of safety and comfort for passengers. Physical limitations, such as low bridges do not seem to offer insurmountable obstacles to their use, although there are other considerations which would seem to limit their field of operation to heavy traffic lines. Numerous unsuccessful attempts to apply in practice the theory underlying the use of this type of equipment should not discourage careful consideration of its adaptability.

Consideration of the size of transportation units brings up the question of train operation. Two or three cars operating independently generally cause more congestion than if coupled in a train. Special conditions, such as short blocks causing frequent overlaps of trains on cross streets in the congested district, would make train operation inadvisable. Aside from special conditions, however, increased train operation will reduce congestion, and where traffic and other conditions justify, trains should be used. Train operation brings up the question of dead trailer versus multiple unit operation. Maintenance of better schedules and comfort of rear car passengers, especially on hill lines, would seem to indicate the desirability of multiple unit operation, in spite of the increased cost of investment, power and maintenance. One railway company is experimenting with two cars having a communicating passage way connected over an intermediate truck, the whole unit carried on three trucks, giving a passenger capacity of nearly double one car with a greatly increased labor economy, two men operating the entire unit. Its large overhang, however, would prevent its use on curves in narrow streets.

In some instances, the use of multiple-unit equipment has been avoided by installing two motors on each of two cars of a permanent train. In this way the advantage of power on each car is gained without the disadvantage of the increased cost of multiple unit equipment.

Left hand turns of all vehicles—particularly street cars—should be avoided, especially in double traffic direction congested streets. Where lines are looped back in congested areas, this means a left hand curve and crossing of all cars at the initial point of the loop, but when this crossing can be made at a less congested point, it will be justified by the elimination of three left hand turns in the more congested locations.

Special attention should be paid to delayed and bunched cars about to enter the congested area. When cars are bunched by a delay on outlying lines, their operation together through the congested area will impair rather than improve the service. Grade crossings of steam railroads are a prolific source of this cause of congestion. Facilities for turning some of the bunched cars short should be made and used promptly when needed.

A car fender projecting four feet beyond the end of car will reduce track capacity on straight track about ten percent which is increased by the interference between projecting fenders and other vehicular traffic near curves. At least ten rush hour passengers out of every hundred have to hang to straps because of such fenders.

Large interurban cars geared to high speed, with long stairway entrances difficult to board and leave, and entirely unsuited to operation through congested streets with frequent stops, should be eliminated.

Track and overhead facilities, particularly switches, should be kept in the best condition to prevent failures and delays.

The street parade has always been the bugaboo of the street railway man; not so much on account of the trouble it makes for him, but because of the senseless manner in which it is frequently allowed to interfere unnecessarily with the comfort, business and convenience of thousands of people. Parades cannot be eliminated, but they should be routed so as to produce the desired results with a minimum of interference.

Well equipped trouble wagons centrally located with proper signal or telephone facilities, should respond promptly to calls for help. Every large property should have hose jumpers for relief from blockades by fire hose.

Finally and most important is the spirit of "let's go" in the operating personnel. To the extent that employes can be interested in trying to put cars over the road, to that extent will it be possible to take advantage of every opportunity to reduce congestion. Without their interest, nothing worth while can be done. With their interest, anything within reason can be done.

Co-operation by the company and its employes with those charged with the enforcement of traffic regulation should be established.

Correct measurements, calculations and conclusions regarding the physical problems involved are essential but easy as compared to the real job of dealing with the human element in such a way as to make the physical property valuable to the car rider and the company and, therefore, to the community.

Use and Abuse of Electric Motors

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IN THE USE of electric motors, it is difficult to establish the point at which abuse starts. All railway operating men recognize the necessity for a certain amount of maintenance work on railway motors, but it is sometimes difficult to establish the line at which maintenance expense passes normal and becomes excessive. The dividing line between proper maintenance expense and undue trouble is constantly shifting. It shifts due to changing operating conditions; service that today seems abnormal, tomorrow becomes normal. It shifts due to improvements in design and construction; motors that have certain limitations today are tomorrow replaced by motors having those limitations removed or at least raised. The last few years have demonstrated clearly what a large effect the character of the available labor supply has on maintenance. The conscientious and intelligent workman not only does a given overhaul job more economically, but he does it better. A repair job, poorly done, often starts a series of other troubles. In view of all of the variable elements involved it is impossible to set up the same standards of inspection and maintenance on all properties. Each group of operating men must analyze the local service requirements and arrange to give the particular equipment that is in use an amount of inspection and care that will result in maximum service and minimum maintenance expense in the long run.

Recognizing the severe operating conditions and the difficulty operating managers have in securing high-grade workmen, the development of the railway motor has been along the lines of producing a sturdy motor. It must be recognized, however, that an electric motor is fundamentally a structure that requires intelligent attention.

The entire electrical equipment of an electric railway car differs from the other equipment entering into the construction of the car, in that its successful operation is dependent on the integrity of the current carrying parts, the failure of anyone of which causes delay and expense. These parts are composed of material that must be selected, not primarily for their strength, but for other characteristics, as shown in Table I. This clearly indicates why motors require reasonable care both in their application and use.

Abuse is quickly reflected in high maintenance. It may exist either in the application of the equipment or its operation. An example of the former is the case where the leads from the car body to the motor are inadequately supported, so that they are allowed to have too much movement and come in contact with parts of the truck or motor frame. An example of the latter is permitting excessive wear to take place in the bearings before replacement, thereby subjecting the motor to excessive vibration.

The one overshadowing cause of trouble in railway motors is vibration. This vibration originates from track conditions, gear tooth impact and frequent starting and stopping, and is greatly increased by excessive clearance in bearings. Cases have been observed where clearances as large as 5/16 inch have been permitted in axle bearings before replacement. Under such conditions the motor is constantly being subjected to a series of blows that must result in trouble. Axle bearing clearances so large as this are perhaps not common, but serious punishment of the motor starts long before the clearance has reached such a value. Systematic inspection that will bring all bearings up for attention, when they have reached certain

maximum clearance, will pay large dividends in reduced motor trouble.

The railway motor has been very highly developed to meet operating conditions and it will stand as much vibration as any type of motor built, but it can be and is abused in service. Some comparison with motors for industrial purposes may be of interest. In motors of sizes comparable with railway motors, there are two general classes of direct-current industrial motors. These are the so-called general purpose motors that drive line shafts, machine tools, pumps, etc., and the mill type motors used for driving auxiliaries and cranes in steel mills.

TABLE I—THE ELEMENTS OF THE ELECTRICAL CIRCUIT IN A MOTOR

Part	Material Used	Characteristics Governing Choice of Material
Motor leads	Insulation	Dielectric strength Flexibility Ability to resist chafing Ability to resist effect of water, mud etc.
	Stranded copper	Conductivity and thermal capacity Flexibility
Brush holders	Insulation	Dielectric strength Ability to withstand vibration Ability to withstand flashing Ability to withstand heat
	Carbon box brass	Ability to resist corrosion Ability to withstand vibration Conductivity and thermal capacity
	Carbons	Resistance Scouring effect Ability to withstand vibration and blows Ability to stand overloads
Commutator bars and insulation	Copper	Conductivity Ability to resist stress due to high speed Ability to resist blistering on surface
	Mica	Dielectric strength Ability to withstand heat
Armature coils Field coils	Insulation	Dielectric strength Ability to withstand heat Ability to withstand moisture Ability to withstand vibration
	Copper wire or ribbon	Conductivity Ability to withstand vibration

The general purpose motor is suitable for either belted or geared service and is capable of standing up under the ordinary vibration incident to only moderately secure foundations, gears aligned only moderately well and vibration transmitted from the driven machine. The construction of these motors is lighter than that of the railway motor. Attempts to use these motors or some of their parts, such as brushholders, in railway service have always failed, although in the service for which they are designed they give a length of life in excess of that of railway motors.

The same motors gave considerable trouble when used in steel mills, on reversing tables for instance, and this led to the development of the mill-type motor. These motors resemble railway motors, but have even heavier mechanical parts because of the rough service and the great expense incident to any interruption in service. These motors are regularly plugged, often several times a minute, and frequently operate with gearing in poor alignment or with broken teeth. Even these severe operating conditions however fail to punish the motors as severely as does railway service and, as a result the maintenance is lower. The principal reason for this is that the motors are not hauled about over tracks, with the attendant rail end blows, cross-over jolts and stretches of bad track. Poor track maintenance is undoubtedly reflected promptly in high motor maintenance and is one of the worst forms of of motor abuse.

Assuming that all the mechanical conditions—track, gears and bearing clearances—are good, there is still the possibility of seriously damaging the motor windings by improper overloads. There is no great difficulty involved in selecting the correct size of motors for application on cars of a given weight to operate under stated conditions of schedule speed, grades and loads. When, however, such cars are used to push disabled cars up long grades or to clear from the track heavy snow that should be removed by sweepers or plows, the loads on the motors may easily be such as to roast the windings seriously. This condition is particularly true of the light weight safety cars, which are sometimes employed to push in disabled heavy cars or in snow bucking. The motors on these cars necessarily have low thermal capacity. On short time heavy overloads in excess of the rating the temperature, therefore, rises rapidly. A somewhat higher short time load can be carried if the motors are cold at the start than if they are at their normal operating temperature, but the following figures showing the internal temperatures, i.e., at the copper, inside the insulation, indicate that, with heavy overloads the temperature can quickly be brought from cold to an injurious value. In these tests the motor started cold in each case.

Motor rated-37 amps., 600 volts, 60 min., 75° C rise
Motor tested-63 amps, 450 volts, 20 min., 150° C rise
Motor tested-100 amps, 450 volts, 5 min., 175° C rise

Motors having greater short-time overload capacity can easily be applied to these cars but they will weigh and cost more. The use of the lighter motor is good engineering, and the benefit accrues to the user, but it must be matched by intelligent operation.

Too strong emphasis cannot be placed on the wisdom of a policy of maintenance that continually analyzes the conditions, both mechanical and electrical, that the motors are being required to fulfill. Such analysis leads to a clear knowledge of the conditions under which it is more economical to spend money for inspection and attention, than through inattention to allow the equipment to be punished to the extent that much more money must be spent for overhauling.

Shop Facilities for Maintenance of Railway Equipment

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ADEQUATE maintenance of electric railway equipment means much to the operating company, both from the standpoint of reduced costs and also from the standpoint of improved service. Among the principal items for consideration in planning an ideal main repair shop are a suitable location and buildings especially adapted to the work.

The site should be centrally located, and close to both rail and water facilities, with the idea of bringing all the principal work to the shop and using the car houses or depots for inspection and light repairs only. Steam road connections should be brought both into the storage yard and the shops proper, so that all freight, new equipment, etc., can be unloaded or reloaded with the minimum amount of handling.

The buildings should be built of reinforced concrete, or brick and stone with slate or tile roof. They should be of the sawtooth type, high enough to permit the hoisting of car bodies from the trucks by the use of electric traveling cranes. It is highly essential that shops have ample light and ventilation, not only to make them bright cheerful and comfortable for the workmen, but also to speed up the work. They should have open pit construction of reinforced concrete. The floors should be of concrete, except in the motor and truck repair department where they should be of treated wood block. The spacing between tracks should be not less than 5 ft. 4 in. The buildings should be fire proof, and so constructed that their maintenance will be reduced to the minimum. They should include the necessary and proper facilities and conveniences such as lavatory with shower, metal lockers, etc., in order to make the surroundings as agreeable and pleasant for the employes as possible. Special attention should be given to the installation of both the heating and lighting systems. Finally the buildings should be equipped with automatic sprinklers, backed by a liberal and high pressure city water supply, also stand pipes with linen hoses and pails, and a system of auxiliary automatic fire alarms and watchman's signals. The sub-storeroom and tool room should be centrally located, so as to make it convenient for the workmen which again means efficiency and economy.

Special consideration should be given to the grouping of the buildings, as by this means only can we produce the greatest economy and efficiency. In the center of Fig. 1 we have the electric and oxy-acetylene welding department, next the blacksmith shop, the wheel borer, press and wheel lathe, the register room, tool room, sub-storeroom, machine shop including babbitting outfit, then the electrical department where all armature and field winding, coil winding, controller and other electrical repairs are made. The electrical department should have a very large oven used for the baking and drying. Adjoining this department is the motor and truck shop, commonly called the over-hauling shop, where all the wheeling, truck, brake and general overhauling of the entire equipment is done.

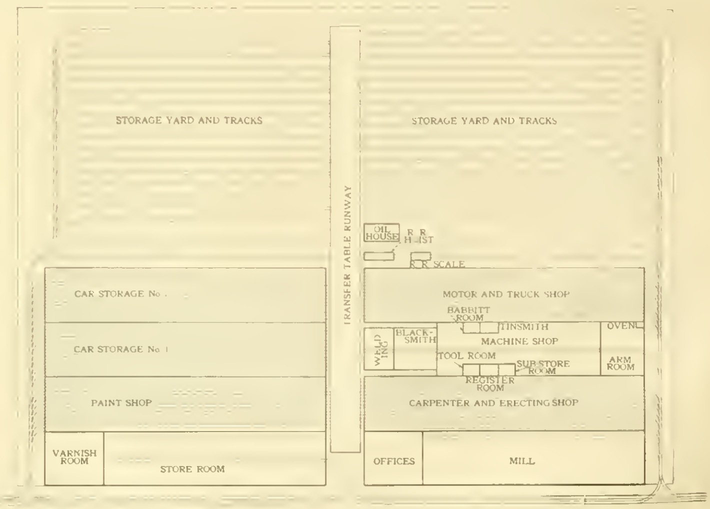

FIG. 1—LAYOUT OF AN IDEAL MAIN REPAIR SHOP

With this lay-out the machine, blacksmith shop, and armature department and sub-storeroom are located so as to make it convenient to make repairs to any part of the car, thus reducing the time element in the handling of material to the minimum. The paint shop should be equipped with racks for the handling of sash, doors, etc., scrubbing machine, adjustable painting scaffolds, washing trays, etc. Special at-

tention should be given to the proper lighting, heating and ventilation so as to assist the drying of the paints and varnish. Adjacent to the paint shop is the main storeroom with adequate facilities for the efficient handling of the many items daily required for the entire property. Two bays adjoining the paint shop are provided for storing open cars and cars requiring general overhauling. The oil and paint storage building, should be fire proof and equipped with modern receptacles and pumps for handling all lubricants, and paints. The track for the steam road should connect with a platform scale of 200,000 lbs. capacity, and a hoist for unloading new cars and heavy material.

MAINTENANCE AIMS

Fundamentally, maintenance begins with the type of car, schedule speeds, grade conditions, etc. These having been carefully considered, it is then the duty of the Superintendent of Equipment to obtain the maximum results for the minimum outlay. High grade materials and careful workmanship should be used in all parts of the equipment, bearing in mind that simplicity and durability are two great factors in reducing costs. By using high grade materials, we not only keep down the weight of the car but prolong the first repair period as well. For instance, a manganese brake shoe head will last at least four times as long as a malleable iron head. Case hardened pins and bushings, babbitt lined journal bearings, manganese bronze check plates, etc., all give much longer life, fully justifying their extra cost.

We should also consider the inter-changeability of parts, the use of jigs for drilling, effective blow-out coils in the control removable finger tips, high grade babbitt in all motor bearings, the under-cutting of all commutators, the use of high grade carbon brushes, all of which help to increase the first life and consequently aid in the reduction of maintenance costs. Another and very important item is standardization, not only from the standpoint of the mechanical department, but of the supply department as well. Therefore, glass of all kinds should be kept to size and thickness, brake shoes, brake shoe heads, wheels, resistance grids, gears and pinions, etc., should be standard. If the angle of helical gears and pinions is standardized, the maintenance costs of the mechanical department will be reduced as the number of spare parts necessary to be carried by the supply department, which consequently reduces the amount of capital invested in idle stock.

Considerable money is wasted by allowing parts to wear down too far. If, for instance, the brake shoes are allowed to run too long, cutting out of the brake shoe head, and excessive flange wear of the steel wheels will result. Thus, thousands of miles are turned off the wheel tread to build up the flange to the proper size and shape. The latter is an exceptionally heavy item and should be watched very carefully. Worn brake lever pins and bushings should be renewed in order to protect the levers. Allowing armature bearings to run too long not giving the waste and oiling the proper attention, failure to watch the condition of the dowels or keys, and the condition of the outside diameter of the bearing and the diameter of the bearing cap or housing, will result in the stripping of armatures and fields, which is another heavy item of expense. Cast iron wheels should be frequently inspected for badly chipped flanges, heavy flanges, cracked spokes and treads, and bad flat spots.

The careless handling of armatures by supply car crews, and the workmen, such as rolling them over rough floors, nail heads, and other foreign particles may cause many failures.

POWER RECORDERS

The installation of power recorders, with the constant co-operation of the Transportation Department, will result in great reduction of maintenance costs. The power recorders in many cases were installed principally to effect a saving in power, but several years of service has proven that due to coasting, the motors are running much cooler, and the life of both armature and fields are prolonged considerably. The life of the controller fingers and burning tips are also increased, there is also much less braking which results in the greater life of the brake shoes and wheels, and incidentally a great falling off in cases of accident damage has resulted.

CONTACTORS

The use of auxiliary contacts in place of circuit breakers has almost entirely eliminated controller explosions, removing at the same time the controller flashing from the platforms of the car. The life of the burning tips and fingers is considerably increased. Another important feature of the contactor, when trailers are used, is the automatic setting of the overload trip. When the disconnecting switch is thrown the air cocks open and the overload trip is changed to the high setting. When the trailer is uncoupled the disconnecting switch is thrown, closing the air cocks and the overload trip is changed to the low setting.

MULTIPLE UNIT OPERATION

Cars equipped with semi-automatic control with straight air brakes having emergency feature, have been operating successfully for several years. The improvements in the design of the switch in the group have lowered the maintenance decidedly; the burning tips of the older switch had to be replaced about every 6000 miles in severe service, while the tips on the improved switch need no replacing under 30 000 miles in the same service.

This type of control can also be arranged, by adding an additional overload trip, to meet the requirements of trailer service, so that when the disconnecting switch is thrown, the range of the overload trip is increased to take care of the additional load. When

the trailer is uncoupled and the disconnecting switch is thrown in the opposite direction, the range of the overload trip is decreased for a single car operation.

TOOLS

The tools and equipment required for handling 1000 to 1200 four motor equipments are listed in Table I. Individual motor drive should be installed where possible to eliminate all shafting and belts.

TABLE I—TOOLS AND EQUIPMENT FOR VARIOUS DEPARTMENTS OF REPAIR SHOP

MACHINE SHOP

1—25 in. heavy duty engine lathe
2—20 in. lathes, same type of control
2—16 in. engine lathes, same type control
1—Speed lathe of any standard type
1—Standard turrett lathe with geared head No. 4
2—Upright drill presses 25 in. swing
1—Single spindle sensitive drill press
1—No. 3 plain milling machine with dividing head and vise complete
1—Standard improved 4 ft. planer with 8ft. table
1—Shaper 16 in. stroke
1—Standard drill grinder
1—Floor grinder to carry grinding wheels size 16 in. by 1.5 in.
1—Floor grinder to carry wheels 12 in. by 1 in. by 1.25 in.
1—Pinion puller
1—Standard cutter and reamer grinding machine
1—Standard boring mill with five point chuck anl 4ft. table
1—Standard wheel lathe
1—300 or 500 ton wheel press
1—Standard double head bolt cutter 2.5 in.
1—Cold cutting saw
1—Standard 36 in. engine lathe, triple gear
1—Up-to-date babbitting outfit
1—500 cubic foot air compressor
Standard line of pneumatics

BLACKSMITH SHOP

1—Furnace
4—Forges
1—Gas furnace for tempering high speed steel
1—Tank for oil quenching of springs, etc.
1—Mohr kerosine torch
1—Heavy pneumatic drop hammer.
1—Punch and shear
1—Shop built crane for the handling of heavy forgings
1—Roads bender
1—Oxy-acetyline welding outfit
1—Electric welding outfit

PAINT SHOP

1—Paint mixing machine
1—Sand blast
1—Cane seat scrubbing machine
2—Large scrubbing and rinsing troughs

CARPENTER SHOP

1—Standard cut-off saw
1—Circular saw with 38 by 58.5 in. table
1—16 in. jointer
1—Standard variety moulder
1—30 in. planer
1—42 in band saw
1—Set automatic band saw guides
1—Jig saw
1—Tenon machine
1—Car straightener
1—No. 1 mortising machine
1—Wood bender
1—Sewing machine
1—Electric riveter
1—Drill press
1—Vertical boring machine
1—Emery wheel

MOTOR AND TRUCK SHOP

2—Traveling cranes with runways
4—8000 lb. triplex chain blocks
4—Armature lifts or trucks
1—Car wheel grinder
1—Portable control rack for running trucks out from car by its own power
1—Special shop built wagon, 3 ft. wide, 10 ft long, for removing compressors, brake cylinders, etc.
2—3000 lb. triplex chain blocks

ARMATURE DEPARTMENT

8—Modern armature winding stands
2—Testing transformer, range 750, 1000, 1500, 2000, 2500 volts
3—Armature yokes for locating short circuits
4—Armature coil winding machines
1—Tapping machine
3—Pneumatic coil presses
1—Small armature yoke for testing short circuits of compressor armatures
1—Universal car tester, type F-2
1—Century field tester
1—Century fault finder
4—Shop built resistance sets
1—Milli-volt meter double scale 0-150 and 0-1500
1—Large oven with dripping pans
2—7 in. I-beam runways with carriages and pneumatic hoists
1—Undercutting or grooving machine with exhaust fan
3—Gas furnaces for heating soldering irons, etc.

SPECIAL TOOLS AND EQUIPMENT

Many hours will be wasted by workmen who do not have enough or the proper tools for handling the work economically, therefore the foreman in charge should see that special tools are kept in the tool room and delivered to the workmen by check. The special tools are to be provided by the company. "Special tools" are off-set wrenches, ratchet wrenches, ratchet screw drivers, off-set socket wrenches, and other tools that will tend toward economy and efficiency. Other special tools that are absolutely essential are jigs for brushholders to see that they are neutral, straight and true, a tool for the machining of absolutely equal halves for armature and axle bearings, the straightening up of the armature air ducts, as well as the flaring out of the armature laminations without the removal of laminations.

The tanks for dipping armatures and field coils should be equipped with a heating coil in order to bring the compound up to the proper temperature and specific gravity, instead of using benzine or gasoline. The latter really destroys the body of the compound, while heating softens it and leaves the body of the compound unimpaired. The best results can be obtained by first baking or heating the electrical apparatus. While hot, place it in the heated compound, allowing it to remain there until thoroughly saturated, when it should be removed, and again placed in the oven for the final baking. The foregoing treatment is especially recommended when armatures are in for minor repairs and have seen several years of service.

MOTORS

If a motor is performing satisfactorily, it should be given proper and careful attention at proper intervals, say between 1000 and 1200 miles, and be allowed to run until the bearings have worn to the safety point. It should then be removed from the truck and put through the usual cleaning and blowing out process. The armature and field coils should be cleaned, dipped and baked. The shaft and commutator should be trued up and the mica under cut. The bearings should be rebabbitted with the best grade of babbitt obtainable. The field coils should be tested and the insulation and strands of the leads put in good condition. The brush holders should be inspected to see that they are not badly worn, that the springs have proper tension, and the shunts are good and tight. All dowels, dowel holes or keys and keyways must be in good condition. If the bearings are pressed in the housings, see that they are put in with proper pressure, and the waste properly packed and lubricated.

The motor should then be reassembled and put back in service. Experience has taught us that the less armatures and fields are handled, the fewer will be the failures and delays, and the greater the reduction in maintenance costs. This applies to the equipment generally, the slogan being "up to the safety point," and this can be accomplished by good and careful inspection by the workmen at the car house, followed up by the car house foremen, the latter being checked up at proper intervals by a general inspector who has had several years of experience not only at a car house, but at the main shop as well.

LUBRICATION

Large quantities of oil and grease are being wasted daily on many properties, and to correct this

we should work with the engineers of the oil companies, in order to follow up the performance of the lubricants. An accurate record should be kept of all lubricants delivered and used during the month at each car house. Then at the end of the month, the mileage credited to each car house, will give the cost of lubricants per 1000 car miles. This will set up a rivalry between the various car house foremen and no doubt will greatly reduce the lubricating costs.

WELDING

Practically all railway men are enthusiastic in both oxyacetylene and electric welding, both of which mean much to street railway companies. Some of the welding that is done is good, but some is not what it should be. After all, in the strict sense of the word, it is not "welding," it is "fusing" or "sticking" and it is an acknowledged fact that much depends on the workman. A blacksmith must know when the material is exactly right for welding. If it is not hot enough the weld cannot be made. If the material is too hot, the material is "burnt" and although he makes a weld, the joint is liable to fail shortly after being put in service. How many welders today, know whether they are burning the material and whether they are using the proper material. This work should be done by a reliable blacksmith; a man who displays good judgement and who is willing to take advice from a metallurgist as to the right materials to be used for making welds on all classes of iron, steel, copper, aluminum or brass.

CAR HOUSE INSPECTION

All cars should be given a brake inspection every night. A standard form of report for each and every car should be made out by the motorman every day, checking off any items that need attention. The night workman should correct the defects that do not require much time. When they require considerable time he should place a shop sign under lock and key upon the brake handle, holding the car for the attention of the day forces. The day force should look after the work left over by the night man or men (we have not more than two night men at any car house) and give the cars a general inspection. The cars are brought in for general inspection every 10 or 12 days, at which time they are carefully inspected from the trolley wheels to the rail, and at this time all light repairs are made. By light repairs I mean the replacing of trolley wheels and poles; placing tips on circuit breakers or contactors; light switches; blowing out and cleaning of controllers; replacing work tips and fingers; replacing carbon brushes and brushholders; taking clearance of armatures; replacing an armature in a split frame motor; blowing out of motors; the cleaning and oiling of brake and triple valves; inspection and repairs to governors; the inspection and oiling of the compressors, brake cylinders and leathers, piping, etc., the inspection and light repairs to the brake levers and pins, and a general inspection of the wheels. By having open pit construction each and every car can be gone over, or inspected every night, or at least every other night. A workman can cover at least seventy cars and still have time to take up brakes and make many other minor repairs. Having been under every car he knows the general condition, and many interesting defects are dicovered that would not have been found from the floor.

MAIN CAR INSPECTION AND REPAIRS

To give the cars a thorough and general overhauling, the proper thing to do is to raise the body from the trucks. A greater portion of this work is done when the car is brought to the shop for wheeling or the turning of wheels. Here the workmen have all the facilities for making any and all repairs from the trolley wheel to the rail; and while the body is removed all parts are accessible and can be easily inspected. Perhaps the most interesting work is the general overhauling of a box type motor. When wheeling a car the body is out of the way, the brakes have been "cut loose," the axle bearing caps and gear pans have been removed and it is only necessary to remove the suspension bolts to remove the motor from the truck.

SUPERVISION

We have discussed the ideal shop with all the latest improved and efficient machinery, tools, etc., as well as conveniences for the employes, and now we get down to the point of supervision.

We must have live energetic men in charge of the various departments, men with good dispositions who are capable of studying the manner and ways of employes, to get their good will, and mingle with them, each of whom should bear in mind at all times that he is their leader and as such is responsible to his superiors.

Discipline must be maintained at all times. However, the man in charge should be ready to meet the employe on any reasonable matter at any time, and if the problem is too big for him, he should advise the employe that he will take the matter up immediately with his superior, and then carry out this promise. In order to manage a shop properly we must have team work, and team work can be inaugurated in a shop or plant only where confidence between those in charge and the employe has been fully established. Experience has taught us that we can have team work among our men and have their confidence and respect by showing them that we have confidence in their work and respect for them. Respect will command better discipline in one day than arrogance will in a month. Discipline built on the proper foundation, and tempered with common sense will result in team work, and is the only kind that lasts and pays above par in efficiency, confidence, and respect.

Construction of Semi-Steel, Front-Entrance Side-Exit Cars

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THE 1920 model car built in the shops of United Railways Company of St. Louis and recently placed in service is of the pay-as-you-pass, front-entrance, side-exit type. Fifty of these cars are now in successful service on a heavy duty line. The car has vertical sides, round ends, arched roof, and is equipped with two double-motor trucks. One important feature of the floor plan arrangement is a single inside step at both the front entrance and the side exit door, made possible by ramping the floor from the step towards the center of the aisle and also along the aisle and away from the door openings. This ramp, which imposes no inconvenience on the passengers, makes possible the use of the single inside step and avoids the use of folding steps or a dropped platform floor. It is expected that this feature of the car will reduce the time of loading and unloading.

The front entrance has a double, two-part, outward folding door, which is air operated. At the side exit there is a double sliding door, also air operated, and each half is independently controlled by the conductor. The entrance and exit doors have a clear opening of five feet and are divided in the center by an aluminum railing, thus providing two passage ways for passengers either boarding or alighting.

FIG. 1—THE PETER WITT FRONT-ENTRANCE, SIDE-EXIT CAR

The conductor's station is at, and just forward from the center exit door. With this arrangement the entire front portion of the car from the conductor's station is available as loading space, as passengers are not required to deposit fares in the fare box until they pass the conductor going either to the rear portion of the car to find seats or in leaving the car. The side exit is located one window space forward from the center line of the car body, thereby increasing the seating capacity of the rear or "paid portion" of the car. This was deemed a desirable feature.

The seating arrangement is a combination of cross and longitudinal seats. The rear portion of the car contains sixteen cross seats and a semicircular seat fitting the round end of the car. The front portion of the car has 27 feet of longitudinal seating. This gives a total seating capacity of fifty-nine passengers. The general dimensions of the car are shown in Table I. The motorman's station is separated from the remainder of the car by a light wood and glass partition provided with a sliding door. Suitable hand rails at the conductor's station facilitate the movement of passengers and the collection of fares.

CONSTRUCTION OF CAR

The car body is of semisteel construction consisting of a steel bottom framing, up to and including the belt rail, built up from standard structural shapes and steel plates. The principal feature in the design of the steel bottom framing is the use of a 12 gage steel plate 30 in. wide reinforced at the bottom with a 3 in. angle forming the side sill and at the top by a 2 in. angle forming the belt rail. This combination forms a girder carrying the entire weight of the car and extends along both sides and around the rear end of the car forming the wall of the car below the belt rail complete, inside and outside, ready for painting.

TABLE I—GENERAL DIMENSIONS

Overall length	50 ft. 6 in.
Extreme width	8 ft. 10 in.
Height from floor to center of headlining	7 ft. 8 in.
Truck wheel base	5 ft. 4 in.
Pivoted distance	24 ft. 6 in.
Total wheel base	29 ft. 10 in.
Height from rail to step	15 in.
Height from rail to top of trolley board	11 ft. 10 in.
Height from step to floor	12.5 in
Weight of car, complete	36 300 lbs.
Seating capacity	59

In the three window spaces in front of the motorman a 40 in. steel plate is used to provide a pocket sufficiently deep to take the three single-drop sash. In the space between the body bolsters the floor is supported by seven cross sills, each made up of a 4 in. channel laid flat and trussed up from the bottom with a 0.5 in. rod and two 9 in. malleable iron queen posts. The reason for this trussed construction is to gain proper clearance for the brake levers and rods without resorting to offsets or bends.

In the space between the rear body bolster and the rear end of the car the floor is supported by two 4 in. channels set on edge and one 8 in. channel placed flat. On the front end of the car the style of construction is similar except for the necessary framing around the step. The floor at this end of the car is supported by one 4 in. angle, one 8 in. channel and one 4 in. channel

placed flat. Suitable wooden nailing strips are bolted to all the steel cross members and also on each side of the steel body bolsters.

For diagonal bracing at each end of the steel bottom framing 2.5 in. angles and 0.25 in. gusset plates are used. To provide additional strength for resisting bumping and drawbar stresses, each end of the bottom frame is re-enforced with a 0.25 by 12 in. steel nose piece cut to fit the round end of the car and is securely riveted to the 3 in. angle which forms the side sill and also extends around the end of the car.

The center portion of the bottom frame is held square by four diagonal tie braces which are attached to the gusset plates. The spaces directly over the trucks are covered with No. 18 gage black sheet steel which is securedly fastened to the bottom side of the floor. This serves the double purpose of a diagonal brace and as fire-proofing the wooden floor.

To carry the load stresses around the door openings, steel framing is used. The center door frame is made up of two 9 in. channels tied together at the top by a 5 in. by 3 in. angle and at the bottom by a 6 in. by 3.5 in. angle all of which are in turn securely riveted to the side plates, belt rails, side sill and cross sills.

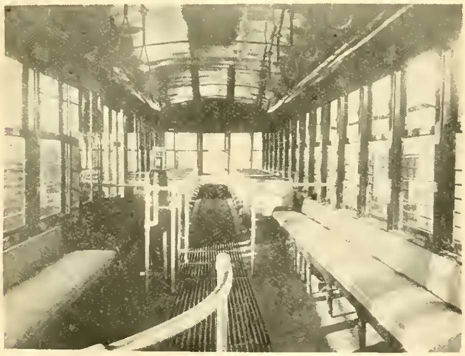

FIG. 2—SEATING ARRANGEMENT OF THE PAY AS PASS TYPE CAR

At each end of the straight portion of the car body, pier posts of 6 in. channels are riveted to the side plates and extend up to the top plate and letter panel to which they are securely attached with bolts. These pier posts together with the steel door frames stiffen and prevent racking of the upper portion of the car body.

Since the steel bottom framing is provided with the necessary strength to resist all ordinary working stresses encountered by the car in service the wood superstructure of the car is made as light as possible. The side posts and car lines are of ash, while the pier post, door frame fillers and floor nailing pieces are of oak. The top plate and flooring are of long leaf yellow pine, the letter panel and drip rail are of poplar.

The carlines at each post are re-enforced with a 1.5 in. by 0.25 in. steel car line with a foot at each end bolted to the top plate. The sash and interior finish is of cherry stained and varnished which harmonizes with the light green headlining and gives the car a very pleasing appearance. The seats, both cross and longitudinal, are of rattan over hair felt and coiled springs.

This car is equipped with two, double motor, inside hung trucks of a new design developed by the Commonwealth Steel Company in co-operation with the Railway Company's engineers. The principal feature of the truck is a main frame made in a single steel casting, eliminating all the usual connecting bolts and rivets and at the same time making it impossible for the truck to get out of square. The truck is of the full equalized, arch bar type similar to those used under Pullman and other steam railway passenger cars, which insures easy riding and freedom from derailment, often caused by trucks not being able to adjust themselves to irregularities in the track.

COUPLING ARRANGEMENT

A built up wood and steel bumper 3 ft. 9 in. wide and extending out 6 in. in front of the car body is provided to form a support for the plain, cast-steel, drawbar pocket and also as a protection for the headlight and front end of the car. The rear draw coupler is made to swing and is of a special design developed by the United Railways Company. The coupler is 3 ft. 8 in. long and pivoted 4 ft. 4 in. from the end of the car. This keeps the outer end of the coupler 8 in. under the car body, making it impossible for boys to stand here and ride. The coupler operates on the bayonet socket principle and no coupling pin is required. The cast steel extension, carried on hooks under the car body, has a T-head on one end which is inserted in the open end of the coupler and given a quarter turn. The other end of the extension is made flat to fit the coupler pocket at the front end of the car. This front coupler pocket is standard on all of the Company's cars and the use of the extension makes it possible to couple the new car to any of the older types of cars.

ELECTRICAL EQUIPMENT

The electrical equipment consists of four 25 hp motors, a controller with ratchet switch for operating the line switch and the safety door interlock system. A magnetic blowout main switch is placed in the motorman's cab for use in opening the main power circuit by hand when desired. The overload relay on the line switch takes the place of a circuit breaker and causes the line switch to break the circuit under the car, thus eliminating all noise and flash from the car interior.

The safety door interlock system makes it impossible to start the car until all doors are closed. Should the power be thrown off for any reason while the car is moving, with the controller handle on any but the first point it is necessary for the motorman to return the handle to the first point before the line switch will close the circuit. This is an additional safeguard against injury to the motors or other equipment.

Side Wear of Carbon Brushes on Ventilated Railway Motors

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When the ventilated railway motor first came into use, there was considerable discussion regarding the amount of dust and dirt that would collect and settle inside the motor, and its effect upon the insulation and the efficiency of the ventilation. Some operators contended that the motor would be kept cleaner due to the current of air passing through it, basing their statement on their experience with some of their non-ventilated motors operating with top and bottom commutator covers open, which gave practically no trouble from dirt collecting inside the motor. Other operators were skeptical and predicted that this type of motor would collect dirt and foreign particles which in due time would give more or less trouble.

After several years of operation, experience has shown that considerable dirt is drawn through the motor and a certain percentage of it lodges inside. If this statement needs confirmation, a visit to some railway shop during the overhauling period when some of the ventilated armatures are being blown out and cleaned by the use of compressed air would be illuminating. One shop has been fitted up to do this work outside of the building. Another shop places these armatures in an enclosed receptacle which is attached to a suction pump to carry off the dirt during the cleaning process. This same condition, however, applies to all types of motors, except on specially designed enclosed motors. Nevertheless, although considerable dirt lodges in these motors, apparently it has caused no serious trouble to the windings nor has it noticeably decreased the efficiency of the ventilation.

Side Wear of Carbon Brushes—A comparatively short time after the ventilated motors were put into service on a number of properties throughout the country, numerous inquiries were received regarding the comparative short life of the carbon brushes. A typical example is as follows:—"Enclosed you will find sample carbons taken from our motors which have been in service only about four months. We are alarmed regarding the short life of these carbons when compared with the life of carbons of our old type non-ventilated motors which averages from 1 to 1.5 years. You will note that these carbons are badly worn on the sides but show very little wear on the end." Some typical samples of worn carbons as referred to above are shown in Figs. 1 and 2. These represent different grades of carbons received from operators in different parts of the country and indicate that this condition is quite general.

COMPARATIVE LIFE OF CARBONS—NON-VENTILATED AND VENTILATED MOTORS

Non-Ventilated Motors—In the early days, when the plain hard carbon brush was used as a matter of necessity in connection with commutators having flush mica, the brush life was comparatively short, and maintenance on carbons and commutators was relatively high, but these figures were never questioned under these conditions of operation. With the advent of the commutating-pole motor with its improved commutation, undercut mica, and the adoption of high-grade graphitized carbon brushes there was a decided increase in the brush life. In some cases, carbon

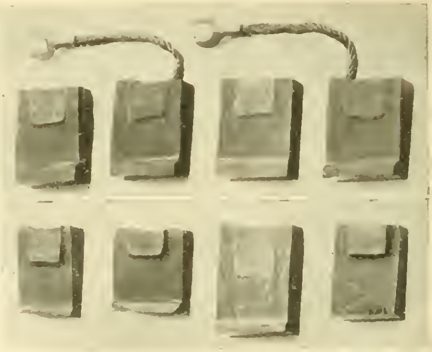

FIG. 1 COMPARATIVE CARBON SIDE WEAR WITH AND WITHOUT SHUNTS

FIG. 2—TYPICAL EXAMPLES OF CARBON SIDE WEAR AS FOUND IN SERVICE

brushes have been reported to have made over 150 000 miles in service. However, in general, the brush life will average between forty and fifty thousand miles or from one to 1.5 years of service.

Ventilated Motors—Facing these facts it is little wonder that some operating men become alarmed when they found it necessary to change the carbons on their ventilated motors after three or four months of service on account of the side wear of carbons which showed very little end wear. This wear has developed on various makes of high grade carbons on different types of ventilated motors and is not confined to properties in any definite section of the country. However, with some types of ventilated motors on certain properties, this wear is more apparent than on other properties. As was found in connection with the non-ventilated motor, so it is true of the ven-

tilated motor, that carbon brush life varies. On some properties as high a life as 30 000 miles has been reported while on others as low as 4 000 miles. In general, the reported average life is much lower than on the non-ventilated motor, and averages of about eight to ten thousand miles may be taken as conservative figures.

SUGGESTED PROBABLE CAUSE OF THIS SIDE WEAR

Electrical Action—It has been suggested that, due to a heavy current of electricity passing from the side of the carbons to the carbon box, the burning action on the carbon rapidly cuts away the sides, which makes it necessary to renew the carbons before they are worn out lengthwise; this heavy current probably being due to some or all of the following reasons:—

1—Light weight ventilated motor, where all parts are reduced to a minimum with close design limitations.
2—High continuous ratings of the motor, due to the improved ventilation.
3—Close application, working the carbons at high current density.
4—Relatively high accelerating currents.

To check this question of suggested excessive currents being responsible for this side wear, tests were made on ventilated motors of the same type operating under the same service conditions, (1) with carbons having shunts or pigtails to take care of the increased current, and (2) with plain unshunted carbons. The results obtained from these test carbons which were in service approximately three months are shown in Fig. 1 and show practically no difference in the side wear of the two sets of carbons. This indicates that the current carrying capacity of the shunts does not help this condition.

In another series of tests* it was found that with the carbon box lined with insulating material, the carbons in these boxes showed signs of side wear. These tests seem to confirm the fact that the wear exists where there is no transfer of current from carbon to carbon box.

Shape of Contact Tip on Pressure Finger—It was suggested by one of the carbon manufacturers that the shape of the contact tip on the pressure finger might be partly responsible for this side wear. To check this point, tests were made on a number of different types of tips as outlined below:—

1—Rounded face extruded metal tip, as follows:—
a—With ears extended over side of tip, Fig. 3.
b—With ears flush with side of tip, Fig. 4.
2—Flat riveted tip, Fig. 5.
3—Adjustable flat tip, Fig. 6.
4—Flat brazed tip, as follows:—
a—Bearing flat on top of carbon, Fig. 7.
b—Bearing on inner edge of top of carbon, Fig. 8.
c—Bearing on outer edge of top of carbon, Fig. 9.
5—Wide, flat, brazed tip with edges well rounded, Fig. 10.

On account of the troubles experienced in connection with the operating conditions under which these tests were made, results were not conclusive, but all of the tendencies seemed to indicate that the shape of the tip had no effect on the side wear of the carbons. One thing in connection with these tests that showed up very noticeably was that the flat tip developed very little destructive action on the top of the carbons.

Mechanical Action—It has been intimated that this side wear might be caused by mechanical action brought about by the constant rubbing and chafing of the carbons against the side of the brushholder box, due to some of the following reasons:—

1—Large initial clearance between carbon and carbon box.
2—Uneven commutator surface.
3—Commutator out of round.
4—Too light spring pressure.
5—Rough finish on inside of carbon box.
6—Worn and loose armature bearings.
7—Severe service conditions.
8—Run down condition of track and road bed.
9—Careless handling of the equipment.

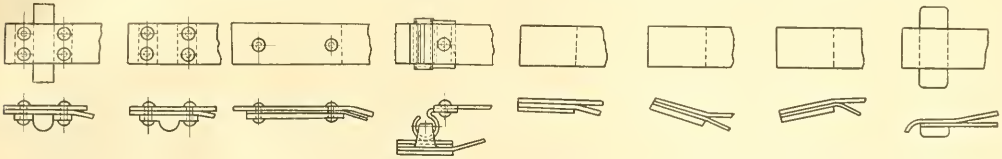

FIG. 3 FIG. 4 FIG. 5 FIG. 6 FIG. 7 FIG. 8 FIG. 9 FIG. 10

VARIOUS TYPES OF CONTACT TIPS AND BRUSHHOLDER PRESSURE FINGERS

All of the above will tend to cause more or less wear on the sides of carbon brushes, but it must be remembered that all of these conditions are also found in connection with the operation of the non-ventilated motors, which would indicate that this alone is not responsible for the side wear of the carbons on the ventilated motors.

Action of Dust and Dirt—By a careful study of this subject from all suggested angles and by means of a process of elimination, the one outstanding factor characteristic of the ventilated motor which is not associated with the non-ventilated motor is the comparatively large amount of dust and dirt being drawn through the motor by the action of the ventilating fan. Observations and tests which have been made from time to time have produced some confirming evidence which indicates that dust and dirt play an important part in the side wear of carbons. These are as follows:—

*Non-Ventilated Motor—Operating with Top Covers Off**—

1—Pronounced streaking was found on the sides of the carbons.
2—The above condition (1) was noted on carbons in

*Explained in detail in an article on "The Action of Dirt on Railway Motor Carbons" in the JOURNAL for March, 1918. *Ventilated Motors*

insulated boxes where there was no passage of current between the brush and the box.

3—With dust and dirt chutes provided for brushholders, no streaking was found.

Sand particles were found lodged in grooves on side of carbon.

1—A comparatively large amount of dirt was found inside of the motor.

2—With dust and dirt chutes provided for brushholders, the side wear was reduced.

3—More rapid side wear was noted in the summer than in the winter, indicating that the condition of the surface of the road bed enters into the question.

4—There was a noticeable difference in carbon side wear, depending upon the location of the air inlet on the motor frame.

5—Straining the dirt at the air inlet reduced carbon side wear.

6—On single-end-operated cars, carbon side wear was more pronounced on Nos. 3 and 4 motors than on the Nos. 1 and 2 motors.

RESULTS OF SERVICE TEST

Under the sub-heading of "Ventilated Motors" the statement covered by condition (1) was discussed in the beginning of this article and needs no further comments. Conditions (2) and (3) were arrived at by service tests and observation. The remaining three conditions will be discussed more in detail to give the available information leading up to these statements.

Types of Ventilated Motors—Condition 4—The earlier designs of ventilated railway motors were laid out with what is commonly known as the series type of ventilation. The air is taken in at the pinion end top side of the frame, drawn forward through the air-gap and around the field coils and then back through the longtitudinal air ducts in the armature to the rear of the motor where it passes out of the frame as shown in Fig. 11. With this type of ventilated motor, the carbon side wear is not so noticeable.

In later designs of ventilated motors, the ventilating scheme was changed to improve the efficiency of the ventilation and is known as the parallel-type ventilation. With this system the air is drawn in at the commutator end through a hole in the housing or motor frame, part passing through the air-gap and around the field coils, and part passing through the longitudinal air ducts in the armature. By the action of the larger diameter fan all of the air is blown out at the rear of the frame, as shown in Figs. 12 and 13. With this later type of ventilated motor, carbon side wear is more pronounced than with series ventilation, possibly for the following reasons:—

1—Increased amount of air—approximately 40 to 50 percent more volume of air than with the series type of ventilation.

2—Less opportunity for dirt to settle before reaching the brushes.

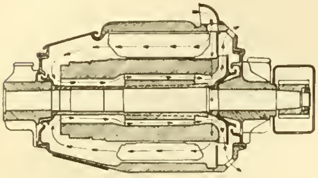

FIG. 11—SERIES VENTILATION

Armature with single fan and longitudinal air ducts. Air inlet located at pinion end top side of housing.

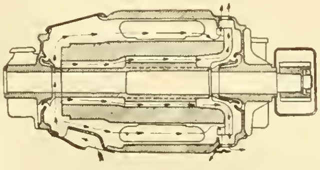

FIG. 12—PARALLEL VENTILATION

Armature with fan and longitudinal air ducts. Air inlet located at commutator end under side of housing.

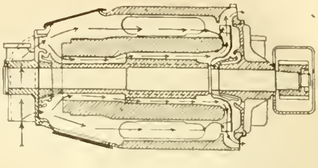

FIG. 13—PARALLEL VENTILATION

Armature with fan and longitudinal air ducts. Air inlet located at commutator end under side of housing.

Straining the Air at Inlet of the Motor-Condition No. 5—In connection with air brake systems it has been found necessary to use a strainer filled with curled hair to provide clean air. This idea suggested to a master mechanic the thought that straining the air at the inlet of the motor would clean it and reduce the carbon side wear which previous observation and tests indicated was due to dirt. Tests were made on a car equipped with ventilated motors having the parallel type of ventilation and the air inlets packed with clean curled hair, such as is used in the strainer on the air brake system. Reports from this test show the following conditions and results:—

1—The life of the carbons was trebled.

2—The commutator and brushholder wear were reduced.

3—The ventilation of the motors was still sufficient for the service.

TABLE I—DEGREES INCREASE IN TEMPERATURE PRODUCED BY A CURLED HAIR STRAINER

Armature Core	Armature Copper	Series Field	Commutating Field	Commutator	Frame
2.5	5	11.5	11.5	7.5	5

These motors are regularly inspected, and when the curled hair becomes clogged with mud and dirt it is removed and new hair installed. To show to what extent this curled hair strained and kept the dirt from passing through the motor, samples before and after using, and also some of the strained dirt, were photographed and are shown in Fig. 14. This test indicates

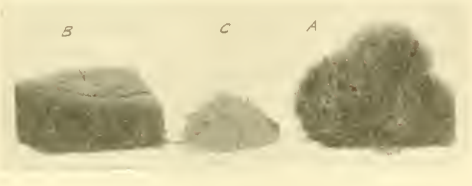

FIG. 14—CURLED HAIR BEFORE AND AFTER USING

A—Clean curled hair before placing in air inlet.
B—Curled hair with dirt collected in service.
C—Fine dirt collected by curled hair in service at air inlet.

that when only clean air is allowed to pass through the motor the side wear of carbons is greatly reduced.

Comparative shop tests were made on a ventilated motor without and with clean curled hair which shows an increase in temperatures as measured by a thermometer, due to the air inlet being filled with clean curled hair, as given in Table I. These figures cannot be used as final, as it will naturally follow that as the hair gets filled and clogged with dirt the temperature will increase until the danger point is reached. Where the air is strained by this means there is danger of reducing the efficiency of the ventilation and producing overheating of the motors, and this would be more serious than removing a few carbons on account of side wear. Therefore, it should be definitely understood that this practice is not recommended as a general remedy for side wear of carbons. Common sense will tell the railway operating man that under certain conditions this scheme may work satisfactorily, but in general it should not be followed as common practice.

Side Wear as Affected by Position of Motor on Car-Condition No. 6.—A strong current of air is carried along with a moving street car, sweeping with it particles of dust, which may entirely envelop the rear end of the car. With dirty streets and on dusty roads in the country this condition is most pronounced. On the other hand, on well sprinkled streets and oiled roads the dust and dirt are settled and this condition is practically eliminated. A study of side wear on carbon brushes, in connection with the above condition shows a very marked difference in the carbon side wear of the various motors mounted on the same car. This is especially noted in the case of cars running in one direction, on which the carbons of the motors on the rear truck wear more rapidly on the side than those of the leading truck. This is brought out fairely in Figs. 15 and 16, which shows a set of test carbons operating in city service, with single end operation of parallel type ventilated motors, all carbons being of the same grade. The tests were made in the south during the months of August to December. The mileage and average side wear of these carbons is given in Table II. These tests tend to show that the action of the dust and dirt has something to do with carbon side wear. The No. 3 and No. 4 motors on single end cars, always being on the trailing truck, where they are subjected to more dust and dirt, develop more rapid side wear of carbons than the No. 1 and 2 motors on the leading truck.

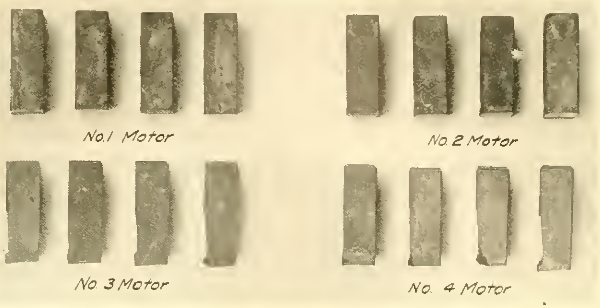

FIG. 16—SIDE VIEW OF CARBON BRUSHES
Showing side wear.

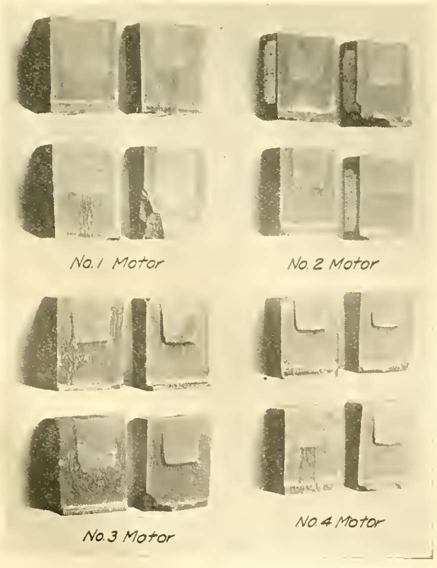

FIG. 15—FRONT VIEW OF CARBON BRUSHES
Showing side wear.

TABLE II—EFFECT OF POSITION ON CAR ON SIDE WEAR

Position on Car	Motor No. 1	Motor No. 2	Motor No. 3	Motor Motor
Mileage	6524	6524	6524	6090
Av. Side Wear	0.006″	0.012″	0.068″	0.073″

CONCLUSIONS

We are not justified in making the positive statement that all carbon side wear is caused by the action of dust and dirt. Associated with the dust and dirt is the ever-present mechanical vibration, and no doubt some burning action due to the electrical current, all of which are contributing factors. However, we believe that the evidence shows that, if the action of the dust and dirt could be eliminated, side wear on the carbons could be obtained which would compare favorably with conditions now existing on the non-ventilated type of motors. It must be borne in mind that side wear of carbons is relatively unimportant, when compared with the marked advantages of parallel ventilated motors over series ventilated and enclosed motors.

**Explained in detail in an article on "The Action of Dirt on Railway Motor Carbons" in the JOURNAL for March, 1918.

Freight Service on Electric Railways

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THERE are three principal means of hauling freight overland, viz:—by the steam railroad, the electric railway and the motor truck, each of which has its particular field of efficiency and economy, depending upon local conditions and requirements, and the nature and volume of tonnage available. It is generally realized that no single means or method of conveying goods can be expected to fulfill all the requirements of industry and trade, but that there must be a co-operative co-ordination of the various forms of transportation to secure most satisfactory and economical results.

In the future transportation scheme of this country, the electric railway is destined to play an exceedingly important part. The past few years have demonstrated conclusively the value and importance to the communities or districts served, of electric line freight and express service, and as a result shippers are making organized efforts to secure expansion of operations and increases in facilities, and are also advocating and giving their support to legislation tending to remove the unreasonable and unwarranted restrictions imposed by municipalities and other governmental authorities, on electric lines engaged in this branch of service.

Communities which are now served by competing steam and electric roads, are fortunate in that shippers are able to secure not only more expeditious and satisfactory service by using the electric line, when such line is engaged in transporting freight, but by using this service entirely on shipments to and from nearby markets, they are benefitting themselves further by relieving terminals, cars and other facilities of the steam roads of short haul unrenumerative tonnage, thereby enabling such roads to facilitate the movement of and improve service on the more profitable long haul heavy tonnage. Available operating cost data indicates that, in addition to being able to render better and more satisfactory service on short haul freight traffic, the electric line can handle and transport such traffic with splendid net financial results while, on the other hand, the steam road is handling such tonnage at a loss when for destinations less than 75 or 100 miles distant. This is due to the fact that the steam road, by the very nature of the service which it is called upon to render, must provide rolling stock, road bed, track and terminal facilities of sufficient size and capacity to take care of maximum demands and to enable them to take advantage of the economies resulting from the hauling of heavy tonnage trains. This heavy and expensive equipment must also be used for hauling the comparatively light loads for short distances. It has been found that the average loading of merchandise in steam road cars is but 10 000 lbs. for which equipment having a capacity of from 60 000 to 100 000 lbs. must be used. Inability to utilize to the fullest extent the tonnage capacity of rolling stock results in expensive operation, which together with the necessarily heavy overhead, interest and taxes makes the handling of short haul business unrenumerative.

On the other hand, the electric railway with its smaller mileage does not require as extensive terminals, nor as heavy equipment, roadway or track, has much less overhead expense, interest and taxes to provide for, and can therefore conduct a freight business profitably, even at the same rates as the steam roads. The revenues from this branch of service are of material aid and assistance in meeting the costs of maintenance, power, supervision, etc. Electric line freight

FIG. 1—60-TON ELECTRICAL FREIGHT LOCOMOTIVE

operation has other advantages to the operators themselves besides the net financial results. It tends to bring about closer relations with communities and individuals along the line, and leads to better understanding and the co-operation of civic bodies, farmers associations, etc., to the benefit of all concerned. Develepement of the feeling that the public and public utilities have common interests, is a valuable asset.

While most electric lines were planned and constructed for passenger service, such construction does not prevent operation of a successful freight business. The territory covered by practically every line will produce tonnage which can be further developed by consistent and intelligent effort through an efficient traffic department. As a common carrier, the electric railway owes it to itself as well as to the communities served, to place at the disposal of the public every facility within its power. Roadway, track, distribution lines and power plants are already in existence, and

other facilities necessary for freight handling, such as terminals, freight rolling stock, and possibly some additions or changes in meeting, passing or other tracks, can be provided at comparatively small expense. Usually no additions to power plant or distribution lines are necessary, as freight trains can be run at

FIG. 2—TYPICAL FREIGHT LOCOMOTIVE FOR LONG TRAIN OPERATION

night or during off peak hours, thereby improving the load factor of the generating station, and at the same time utilizing tracks and other facilities which would otherwise be idle.

In conducting a freight or express business, or both, it is important that special consideration be given to the selection or construction of terminals, motive equipment and other rolling stock, train schedules and traffic department organization. One of the greatest items of expense of freight handling is the terminal or warehouse cost, but this can be reduced to a minimum by a thorough study of the requirements and careful planning of warehouses and track lay-out. It is not necessary or advisable to locate freight houses in congested business districts on property more valuable for other purposes, but experience has shown that no loss in tonnage results from locating in outlying districts on less expensive ground, where sufficient property can be had to provide adequate facilities and permit of future expansion and developement. It has been demonstrated that at larger terminals, greatest economy in operation and efficiency can be secured by having separate warehouses for in and out bound shipments, but where this is not possible, excellent results can be obtained by dividing the warehouse space into two sections; one for unloading and delivering, and the other for receiving and loading. This plan makes for less confusion and delay in making deliveries to patrons, and the floor of the outbound section is left practically free of encumbrances, thus permitting the receiving, weighing and loading of shipments direct from dray into cars.

Decided economies are also possible through providing ample trackage to serve the warehouse. Where tonnage warrants the loading of a number of cars each day, sufficient trackage should be provided for enough cars so that all shipments can be handled direct from trucks to cars with a single operation, thus avoiding extra expense of rehandling. Best results are obtained where two or three tracks are laid parallel to the warehouse platform, with connections for shifting cars at both ends, so that shipments can be trucked through one car into another by bridging at the car doors, and cars can be placed and others taken out without disturbing the entire setting.

Adequate tracks for trucks are also an important part of terminal layouts, to provide for the loading and unloading of consignments by owners. This tonnage is especially desirable both from an operating and revenue standpoint, as practically the entire cost of warehouse labor is saved.

Team tracks as well as warehouse doors should be easily accessible at all times to the shippers' trucks and drays, and of sufficient capacity to take care of the business offered. Delays to patrons' conveyances frequently result in loss of future tonnage.

In the selection of rolling stock for freight service, it is of prime importance that both motive power and trail equipment be suitable for the service to be performed, if most economical results are to be obtained. The number and kind of locomotives and cars to be used can be determined only after a careful study of local conditions and requirements, and the class of tonnage available is known. As a rule however, where a miscellaneous freight tonnage, both carload and less is to be had, and the volume is sufficient to warrant long train operation, or where there is considerable switching service to perform, the electric locomotive is most economical and efficient. In determining the type, size and capacity of a locomotive and its electrical equipment, consideration must be given to track characteristics, curves, grades, weight of rail, strength of

FIG. 3—FREIGHT MOTOR CAR OR BOX-TYPE ELECTRIC LOCOMOTIVE

bridges, etc, as well as to volume and kind of tonnage to be handled; also the maximum current which can be drawn from the substation should be known.

To pull a trailing load of cars weighing a certain number of tons, the motors of a locomotive must be capable of exerting a certain number of pounds tractive

effort or pulling force at the drive wheels. Experience has shown that it requires a tractive effort of approximately 15 to 25 lb. per ton of trailing load to start and bring up to speed a train on a straight level track. About 7 lbs. tractive effort per ton of trailing load is required to draw a train at a speed of 25 miles per hour under the same conditions.

Motor capacity or output is largely a matter of temperatures. A relatively small motor can exert a comparatively enormous tractive effort for an instant, but the heat developed in the windings would be so great that damage would result if operated continuously. A motor equipment may be large enough to haul a train at schedule speed over a long stretch of level track and remain at a safe temperature, but if grades or long sharp curves were encountered, the temperature of the motor might rise to a dangerous degree.

A locomotive must weigh enough so that its adhesion to the rails will enable the motors to exert their normal pulling force. If the locomotive weighs too little, the drive wheels will slip when an attempt is made to pull a load which would otherwise be within the capacity of the equipment. In view of these facts, it is apparent that the maximum pulling force of a locomotive depends principally upon its weight and is not wholly determined by the power of the motors. The maximum tractive effort or pulling force that it is possible for a locomotive to exert is equal to from 25 to 35 percent of the weight on the driving wheels, which is modified by the condition of the track and the design of the locomotive. If a locomotive is too heavy for the capacity of its motors, the weight on the drivers is excessive, and the motors will be overloaded before the drivers will slip. However, in general, if the weight of a locomotive is properly proportioned in relation to the power of the motors and the service requirements, the drive wheels will slip if an effort is made to draw an excessive load, and no harm will result.

The proper electrical equipment for a freight motor car or box car type of locomotive is determined in the same way. This type of car is especially suitable for handling merchandise or trains of from three to six trailers, as it can be used for single unit operation as well as for hauling trains, and at the same time carry revenue producing tonnage. Where business consists principally of less than carload freight or light carload commodities, the motor freight car will probably best meet the requirements. For through service between terminals or large shipping centers, a heavy motor car not less than 40 ft. in length and 60 000 lb. capacity, capable of hauling three to five trailers, will usually be found most economical, while for service requiring frequent stops, a lighter type of motor car will give best results.

To give most satisfactory and economical service, locomotives or motor freight cars should be equipped with slow-speed field-control motors, and helical gears with maximum gear ratio. It is neither necessary nor desirable that freight trains be moved at a speed exceeding 25 miles per hour, and as a general rule there is nothing gained by running faster. The gain in revenue and economy of operation from heavier tonnage handled in slower trains will quickly offset the cost of providing sufficient and adequate meeting and passing tracks.

All freight rolling stock, including locomotives, motor cars and trail cars should be equipped with couplers and air brake rigging suitable for train service, to permit of train operation and the handling of steam road equipment in interchange or switching movements. Methods of loading, dispatching and scheduling freight trains all have an important bearing on final net results of freight handling. Studies of operating methods on electric lines have in some cases developed the fact that while the net financial results covering the entire service for a stated period have been very satisfactory, still better net revenues could be obtained by changes in methods of dispatching, loading of cars, longer train operation, or the use of more modern equipment, and this without in any way impairing the value of the service to the shipper.

There are today, a number of examples of successful freight operation among the electric interurban lines of this country. The average ratio of operating expense to gross freight revenue, where results have been studied and economies effected through proper supervision, is from 70 to 75 percent. This expense includes a proportionate share of the cost of maintenance of roadway, track, overhead lines, buildings, power generation and distribution, superintendence, and any other facilities used jointly with other branches of service, and all expense of maintenance, operation, labor, etc. properly chargeable to freight operation only.

An efficient, properly directed traffic department is indispensable to successful freight operation. This department is in position to know the needs of patrons, their individual peculiarities and requirements, and is responsible for increasing or losing tonnage, and should therefore be consulted and have equal voice with the transportation department in deciding upon service to be rendered, scheduling of trains, distribution of equipment, and the settlement of all questions which may arise effecting transportation relations with the public. This department is also entrusted with the burden of securing new business, locating new industries on the line, co-operating with local civic bodies and associations for mutual benefit, compiling and publishing tariffs, arranging joint through rates, divisions and schedules, and in fact meeting and satisfying the public on all matters connected with the transportation of goods.

Safety Car Operating Results

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A STUDY of the operation of safety cars yields a great deal of very interesting and gratifying data. From practically every viewpoint, the car has proven a success. It has come to occupy a distinct field in the electric railway industry and is sure to be of increasing importance. It is inherently more economical in operation than the heavier double-truck or single-truck car which it is supplanting, but its effect has been more far-reaching. The use of the car has not only decreased the operating and transportation expenses, but more frequent and more rapid service has been supplied the patrons, resulting in a consistent increase in gross revenue. The degree to which these advantages occur may readily be seen from a few simple charts, based on recent data from representative operating companies.

PLATFORM EXPENSE

The primary reduction in expense results from one-man operation. The elimination of one man from the crew has nearly halved the platform expense. In order to give the car operator a share in the advantages of safety car operation, it has been the general practice to increase his rate of pay approximately ten percent above that of a platform man on two-man cars. Compensation for the smaller seating capacity of the light-weight car has been made by an increase in the number of cars on the line. There has thus been an increase in the total number of car-hours of operation, which partly offsets the reduction of man-hours accomplished by using one man per car instead of two. In many cases, the increase in schedule speed has allowed more trips per car and a decrease in headways without a proportional increase in the number of car-hours. The increased revenues resulting from the increased operation have in general fully justified the increase in car-hours. In general, there has been a decrease in total platform expense of 25 percent, which takes into consideration the increase in car mileage and increase in schedule speed. A saving per car-hour in platform labor of 45 percent, as shown in Fig. 1, would result if safety cars merely duplicated the previous service.

MAINTENANCE EXPENSES

As a result of the decreased weight, there is a corresponding decrease in equipment maintenance expense. The standardization of apparatus and the ease of overhauling contribute also to the reduction in the expense for repairs. A single truck is obviously less expensive to maintain than the two trucks of a double truck car. However, the comparison is not confined to double-truck cars. Improvements in the truck and car body design have largely eliminated the galloping and rocking prevalent with the older types of single-truck cars. A considerable decrease in the wear and tear on the car and equipment results in a reduction of maintenance expenses, in addition to savings attributable to decreased weights. Data supplied by companies which keep segregated costs for safety cars and two-man cars show approximately a 40 percent saving. A reasonable cost for maintenance of safety cars under present labor and market conditions is found to be approximately 2.0 cents per car-mile, with average operating conditions.

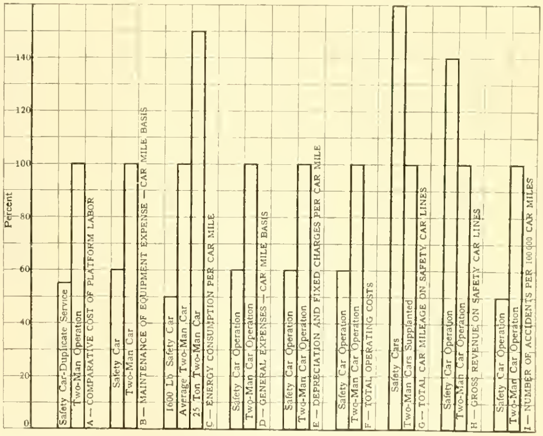

FIG. 1—OPERATING RESULTS OF SAFETY CARS AND TWO-MAN CARS

Track repairs attributable to safety cars are appreciably less than for the older types of cars, on account of the lighter weight of the rolling stock. It is difficult to obtain accurate records of the savings resulting, because the costs extend over a long period of time and, in most cases, various types of cars operate over the same tracks. It is estimated that safety cars effect a saving of 30 to 40 percent in this item.

ENERGY CONSUMPTION

Many tests have been made to show the savings in energy consumption resulting from the use of the safety car. Results have been expressed to include energy for running the car, total consumption at car, including energy for lighting, heating and auxiliaries, and line losses from car to substation. The energy

consumption is roughly proportional to the total weight of car and load. In some cases, where heavy cars were replaced, the safety car consumption is as low as one-third that of the equipment supplanted. On the average, the saving amounts to approximately 50 percent of the original consumption (*C*, Fig 1). The actual power consumption will, of course, depend largely upon the class of the service and the severity of grades. The theoretical power consumption with ordinary service on a level route is approximately one kilowatt-hour per car-mile. For all classes of actual service, an average value of 1.25 kw-hr. per car-mile is reasonable for power consumption at the car. Including power for light, heat, and auxiliaries, the total power consumption at the car will be approximately 1.75 kw-hr per car-mile. The average distribution losses will be 10 to 15 percent of the power used by safety car. In addition to the saving in operating expenses, safety car operation decreases the load on the power system. This may be very important when generating and converting machinery are overloaded. The lower power demand reduces the voltage drop in the distribution system, increasing the average voltage at the car and at the same time improving the efficiency of distribution. The necessity of installing additional feeder copper may often be avoided by the initiation of safety car operation.

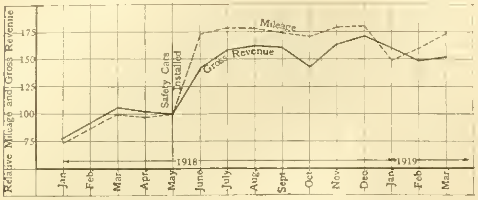

FIG. 2—EFFECT OF CAR MILEAGE UPON REVENUE

GENERAL EXPENSES

Ordinarily there will not be much reduction in total general and overhead expenses. However, in view of the increased service and increased traffic attending safety car operation, the unit charge is reduced. On the basis of the increased car mileage of 60 percent as given in the discussion of gross revenue, the general expense per car mile is reduced approximately 40 percent (*D*, Fig. 1).

Depreciation and fixed charges vary in proportion to installation costs. Original costs in turn vary approximately as the weight of equipment. Although the cost per safety car is much less than that of the two-man cars replaced, more cars are generally provided to supply the increased service. The net effect is that the total fixed charges and depreciation will be reduced approximately 40 percent.

TOTAL OPERATING COSTS

On properties of different size and with different conditions of operation, total operating costs will vary within wide limits. Similarly, the total savings resulting from any change in methods of operation will vary considerably. Many operators have been prompt in taking full advantages of the possibilities of the safety car. Figures submitted for gross savings per year and also records of segregated costs show that an average saving of 40 percent of the total operating costs on a car-mile basis (*F*, Fig. 1) is conservative. One operator in the East recently reported a saving in platform labor alone equivalent to more than $2000 per car per year. While this is undoubtedly the largest single item of savings, it is estimated that on this property there will be an additional saving of $2000 in other operating expenses. The present cost of a standard safety car is approximately $6500. After allowing for fixed charges, it is readily seen that these savings will retire the original investment within a few years, after which the savings will apply as a net gain.

PASSENGER REVENUES INCREASED

Not only have substantial savings been shown in operating expenses, but safety cars have consistently stimulated traffic, even under adverse conditions. The increase in riding is chiefly a result of the decreased headways supplied by safety cars. The increase in number of revenue passengers hauled has been found to be almost a direct function of the increase in service supplied, up to certain limits. Although a few railway companies have instituted safety car service upon a car-for-car basis, most of the operators have increased car-mileage from 25 percent to 100 percent. The average increase has been probably 60 percent. It has rarely been found profitable to increase service beyond 100 percent. Although one of the principal factors in increasing riding has been the securing of passengers who would walk a relatively short distance rather than wait for a car, no doubt the newness and attractiveness of the car have contributed a considerable share. The service has been improved also by increases of 15 to 20 percent in schedule speed. The easy riding characteristics of the car, as compared with older types of single-truck cars, have played an important part by holding the passengers once obtained.

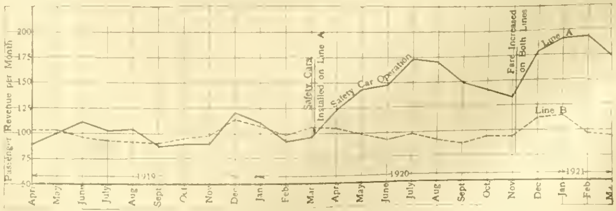

FIG. 3—INCREASE IN REVENUE RESULTING FROM SAFETY CAR OPERATION

The seating capacity of the standard double end safety car is 32, and that of the ordinary two-man cars replaced is from 30 to 50. While the capacity of each car substituted is less, the increased car-mileage gives a seat-mileage as great as or greater than before. It is estimated that on the average, the 60 percent increase

in service provides 15 to 25 percent increase in seat-mileage. The seat-mileage is not only increased, but is better distributed so as to better serve the needs of the public. The increase in the number of units provides more flexibility of operation.

The increase in revenue is of course directly proportional to the increase in paid passengers. Revenue increases up to 75 percent have been reported for the lines on which the safety car has supplanted the two-man car. The average increase in gross receipts, corresponding to the increase in service of 60 percent, is estimated from a number of published reports to be 40 percent. Both the increase in revenues and the decrease in operating expenses act to decrease the operating ratio.

The effect of increased car-mileage upon the passenger revenues is illustrated by the records for one of the lines in Bridgeport, Conn., where safety cars were adopted in May, 1918. The curves in Fig. 2 are based upon these records and are of especial value in depicting actual results. The number of passengers, as indicated by the gross revenue, varied almost directly as the car-mileage of the line, and the effects were obtained immediately. Corresponding to the maximum increase of service of 80 percent, there was an increase in revenue of from 60 percent to 70 percent.

FIG. 4—SAFETY CAR SERVICE FOR HEAVY TRAFFIC AS WELL AS LIGHT

ACCIDENTS

The appropriateness of the name *Safety* is brought out by a study of accident records. It had been suggested that there would be more probability of collision with other vehicles, on account of the higher rates of acceleration generally used and because the motorman's attention would be at least partially distracted from operation of the car by collecting fares and making change. However, this has not been found to be the case. The number of accidents has in most cases been reduced approximately one-half. Several operators report that a large proportion of the safety car accidents are trivial. The safety devices have practically eliminated door and step accidents on many lines. A reduction of accidents is important from a financial point of view, for the costs of accidents have been correspondingly reduced. The importance of accidents is emphasized by a recently published estimate that approximately 4.6 percent of the gross revenue of electric railways is paid out to satisfy accident claims.

RESULTS WITH SAFETY CARS IN SHARON

Some very interesting data* showing the effect of safety cars in stimulating traffic were obtained by the Pennsylvania-Ohio Electric Co. The curves in Fig. 3 are derived from this data, showing the passenger revenue per month on one of the safety car lines in Sharon, Pa., one year before and one year after the introduction of safety cars, and the variation of passenger revenue on one of the two-man car lines in Sharon for the same period. The averages of revenues for April, May, and June, 1919, are taken as 100 in each case. It will be seen that the traffic had the same general characteristics for the two lines during the first half of the period taken, when two-man cars were used on both lines. The same seasonal variations occur, indicating that the traffic conditions on the two lines are comparable. Safety cars were installed on line *A* in April, 1921. From this time, line *A* shows a very decided increase in revenue. It is notable that during the same time the revenues on line *B* show a decrease in comparison with the preceding year. This decrease has been attributed to the industrial depression prevailing, which would be expected to affect both lines in a similar way. An increase in fares in December, 1920, is responsible for a rise in both curves. The decrease in revenue following the change in fares corresponds to the seasonal variation of the preceding year. The number of paid passengers on line *A* was approximately 45 percent greater for the year following safety car operation than for the year preceding, in spite of the industrial depression and the higher fare existing during part of the period. The actual increase in passenger revenue, taking account of the higher fare, was approximately 60 percent.

CAR OF PRESENT DESIGN SUCCESSFUL

There has been no pronounced case of failure of the safety car to disparage the many favorable reports. Although some opposition from trainmen has been anticipated, the service has in practically all cases been instituted in such a way that the occasional objections were soon overcome. There have also been some instances of opposition by the patrons, but these have been removed after a trial of the safety car. Moreover, the results obtained have not usually been due to favorable conditions of operation, for the cars have been adopted for many lines which were showing financial losses or which were handicapped by other difficulties. At the present time nearly 5000 standard safety cars are being used in cities of all sizes, and their field of usefulness is increasing. Occasional suggestions are made for various modifications of the

*Given in a paper by Mr. C. D. Smith, General Superintendent, The Pennsylvania—Ohio Electric Company, before the Pennsylvania Street Railway Association, June, 1921.

design of the standard car, but it is probably the more common opinion that the standard should be continued with substantially the same design. It is especially important that no change should be made that involves any considerable increase in weight, for the light weight has been one of the principal factors in effecting the economy of operation.

While no attempt is made to present the safety car as the cure-all for every street railway ill, and it is not claimed to be the most suitable car for all types of lines, there are many conditions for which it is best suited. As it has done repeatedly in the last five years, it will continue to contribute the difference between profit and loss for many street railway lines.

The Value of Association of the Mechanical Department of Electric Railways

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MOST of us recall how crippled and sick the street railways were during the severe winter of 1917-18, when incessant cold snaps were frequently broken by short warm spells with heavy snows. The streets were either a sheet of ice or a mass of slush and water, and the automobile, so frequently used by the business man, found a haven of rest in the garage. The street railway companies, in many cities, were not only called upon to handle their normal volume of passengers, but had these additional riders to carry as well. The street car tracks, were kept cleared of snow by the street railway company, but frequently were several inches lower than the accumulated snow in the usual vehicular paths, so that the car tracks were the temporary beds of small streams and pools, through which the cars had to be operated. Thus the motors had their windings soaked with water and dirt.

Due to the unusually long siege of operation under these conditions, the equipment failures increased to a point where the railway shops could not keep up with the repairs, and the manufacturers of railway equipment, were also taxed to their utmost. As the result of this condition, about twenty railway operating men, who were in charge of the operation and maintenance of railway equipment throughout the central and eastern states, met at the East Pittsburgh Works of the Westinghouse Company for a consultation with the Company's designing engineers.

After this meeting, it was felt by the railway operating men in attendance, that so much good had resulted from an exchange of ideas, that they resolved to form a permanent gathering. The result is the Association of Electric Railway Men, which includes the master mechanics and equipment men of about forty railway companies in Ohio, Pennsylvania and West Virginia, with a membership roll of seventy men.

This Association holds a meeting in the spring and fall of each year. About thirty-five to fifty men are usually present at each meeting. These men sit around a large table and discuss the operating and maintenance problems submitted by the members themselves in the form of a questionaire (each member being limited to three questions) to the secretary, who lists them and redistributes a complete questionaire to each member from two to three weeks in advance of the date of the meeting.

In this manner each representative sends in questions which are of paramount issue with him, and he knows that his questions will come up for discussion. He will also have a list of the other fellows' problems and will get the benefit of these discussions. He also knows that he must come prepared to discuss any of the questions listed on the questionaire. The manner of conducting the meeting makes it necessary for the secretary, to know each member personally, and all members are subject to call for discussion.

At times the members desire to have a particular problem discussed by representatives of some of the manufacturing companies, in which case, invitations are extended to the manufacturers to have a representative present. Experts on air brake equipment, railway motor maintenance, arc welding, etc. have given interesting talks and the discussions on these subjects are of great value.

The secretary keeps accurate notes and the complete minutes of the meeting are written up and a copy sent to each member. The members can refer to these minutes and can also pass them on to the "boss" to let him know what was accomplished at the meeting. The meeting is always closed in time for a visit to the shops of the local railway company. This visit usually results in a few new ideas being picked up by the members and gives them an opportunity to compare the shop methods in force with their own.

From the nature of such meetings, it is obvious that every member present is sure to gain much valuable information. The equipment man is always concerned in maintenance costs, as his job depends on a good showing, and if he can pick up one or two new

ideas at each meeting, the time and expense of attending the meeting is amply repaid, both to him and his company. Attendance at such meetings puts him in touch with others, so that future correspondence develops. In time of stress, such as a repetition of the troubles of the winter of 1917-18, he may be able to borrow men and supplies, if wanted in an emergency to avoid a tie-up of his equipment.

From the above it will be seen that this Association is conducted somewhat differently from the usual meetings or conventions. With the "round table" discussion, all members soon become acquainted with one another, they speak in their own terms, and give others the benefit of their experience.

The railway companies who send their men to these meetings, benefit by the knowledge gained by their men. The men themselves often get out of a rut, deepened through never having come in contact with others doing similar work and maintaining similar equipment. The manufacturer benefits by knowing whether his apparatus is looked upon with favor in the field, whether it is made accessible for ready inspection and repairs, and whether the parts are strong enough to resist the strains upon them, and if the maintenance cost is excessive.

The fame of the Association of Electric Railway Men has spread, so that the present organizations are beginning to realize the necessity of having equipment men represented in this association. This is emphasized by the Central Electric Railway Association forming under their body, an engineering council and four local engineering sections, namely; the Akron Section, the Toledo Section, the Dayton Section and the Indianapolis Section.

Any engineering organization conducted along plans similar to the manner of conducting the meetings of the Association of Electric Railway Men, should be successful, and other similar associations will, of necessity, form a clearing house, where the members can recite their problems and get together on a sound basis to correct them in the future.

The success of meetings of this kind depends on keeping the sections limited in size, so that the "round table" conference can be maintained and the distance to be travelled reduced so as not to keep the operating men away from their work for more than a day or two at a time.

Some Mechanical Causes of Flashing on Railway Motors

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THE modern commutating-pole type railway motor has inherently good commutation in practically every case. Nevertheless, as every operator realizes, there may be more or less flashing on the average motor in service. Usually this is not bad enough to do any particular damage or cause any real trouble but may, at times, reach serious proportions under unusual conditions. A survey of some of the causes of flashing may give a clue as ot the cause of trouble on a particular road. A flash may be caused in a number of ways:—

a—Interruption and Re-establishment of Power Supply by jumping of trolley, section breaks, etc., while the motor is running. All modern railway motors stand power interruptions on the test floor at all speeds and at voltages far in excess of practical operating condition. For this reason trouble from such causes can usually be traced to some very unusual operating condition.

b—Bucking—This method of stopping a car should be resorted to only in an emergency, for it produces severe mechanical strains on equipment as well as being a frequent cause of flashing. There are some possibilities in control changes to help the motors when bucking is resorted to, but the real remedy is to educate the motorman so that he will not buck the motors unless there is no other way of stopping the car.

c—Salt—In the winter time, when switch points are sprinkled with salt, there is a possibility of salt water entering the motor, getting on the commutator and causing flashing. This is not apt to be a very frequent cause of trouble and can be remedied by proper attention to motor covers.

d—Incorrect Brush Spacing—The effect of incorrect brush spacing is to cause more or less severe sparking, depending upon how far off neutral the brushes are set. If the sparking is severe it may cause flashing and at least it will prevent the commutator from becoming properly polished. The modern railway motor is not apt to give trouble from this source, since the brushholder seats are fixed and the motor is checked for neutral before it leaves the factory. Many of the older motors do not have fixed seats for the brushholders, so that in case of trouble from flashing and poor commutation, the brush locations should be checked.

e—Jumping of the Carbons—If the brush leaves

the commutator surface while the power is on, it draws an arc and generates a cloud of conducting vapor, the amount of which depends upon the distance the carbon is raised, the length of time it is raised, the current flowing, etc. If much conducting gas is generated it may be carried by the commutator, the ventilating air and stray magnetic fields to a point where it reaches ground or the other brushholders and a flash results.

The jumping may be very slight and of short duration, in which case it will result only in slight spitting and sometimes roughening and blackening of the commutator, causing excessive brush wear. Again the brush may stick and the motor commutate through the arc drawn. This may continue for some time without flashing over but of course burns the commutator and brush rapidly. In between lie all degrees of jumping. It is unnecessary to go into any detail as to the effects of the resultant flashing. Every operator knows through sad experience, the evidence of grounded brushholders, burnt wiring around frame and field coils, grounded armatures, bulged field coils, etc. Some of the causes for this jumping of the brushes may not be so evident.

If we assume that the commutator surface is a true cylinder, concentric with the shaft of the motor, and that the brushholders are fixed in position relative to the commutator, then the brushes will remain in contact with it at all speeds. If the commutator is not concentric with the shaft or if it is slightly out of true, the brushes will remain in contact with the commutator at slow speeds, but as the speed increases it will finally reach a point where the brushes will leave the commutator surface for part of a revolution. That is the commutator surface will drop away from the true circle faster than the brush can follow it. This speed depends upon the inertia of the brush and spring mechanism, the friction of the brush in the box and the spring pressure. An occasional high bar or high mica, or a flat spot, will produce the same result, but usually at a lower speed than where the change in the rotating surface is gradual.

Such variations in the true surface of the commutator are frequently met in service. They may be due to a number of causes, such as loose V-rings, variations in individual bars, improper curing, worn commutators, loose bars, etc. Due to the burning that results when the brush leaves the commutator, any irregularity in the commutator surface tends to become worse. The remedy for such a condition is to tighten the V-rings properly, take a light turn off the commutator to true it up, and undercut the mica if necessary. When this is done it will usually be found that a commutator that has been blackened and dirty will take a good polish and assume that chocolate glaze that is so desirable.

Another way in which the brushes may be made to leave the commutator is for the commutator itself to move up or down with relation to the frame. When the armature bearings are worn this will occur every time power is applied or shut off, due to the variation in magnetic pull and the change in direction of the motor torque, or whenever the car goes over any sort of a bump. Worn bearings and gears, loose bolts, poorly adjusted axle collars, loose or tight brakes, are responsible for much trouble of this nature.

Under conditions of loose bolts and worn bearings the ability of the carbon to follow the commutator can be improved by raising the spring tension. Even this will not cure the trouble when conditions are bad, and the general condition of the entire equipment must be improved before satisfactory operation will be obtained. Not only will proper maintenance help flashing conditions but it will improve the general operation of the motors.

Sometimes trouble is experienced from flashing even though the motors and equipment are well maintained. The rails and roadbed may be responsible in these cases. Poorly maintained roadbed, with loose fish plates, bad joints, etc,, will jar the entire motor so much that it may flash due to jumping carbons. Occasionally a very rigid roadbed will cause trouble due to vibrations set up in the equipment, and sometimes corrugated rail is the cause of the trouble.

In attempting to produce motors that will stand these conditions, the designers have been working toward spring mechanisms of lighter weight and fewer moving parts and sliding surfaces in order to reduce inertia and friction, thereby allowing the carbon to follow the movements of the commutator more closely, and thus reduce the length of time the brush is off the commutatator if not eliminate it altogether.

The operator can help himself in this respect by keeping the brushholders clean and their harness oiled, so that there is no sticking or binding at any point in their travel. Carbons should be replaced before they are worn so short that the spring cannot exert any pressure on them. Brush tension should be checked periodically and kept to the proper value to give the best results.

If the brushholders, commutator and motors in general are in good condition and flashing still occurs, higher brush tension should be resorted to. Values as high as 10 to 11 lbs. per sq. in. may be used in some cases with a decided improvement in operation. We might anticipate greater brush wear as a result of increased tension but the experience of a number of operators shows the opposite result to be the case. The life of carbons is equal to or greater than that obtained with low pressure when frequent flashing occurs. The reason is that the reduction in sparking and flashing as a result of the higher pressure materially reduces the burning of the carbons and the improved polish obtained on commutator and brushes reduces the friction and consequent mechanical wear in spite of the higher pressure.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

OCTOBER 1921

Electric Welding as a Factor in Reclamation

As a matter of economy and forced necessity to keep their cars on the road, it has always been the practice of street railway operators to repair in their own shops certain worn and broken parts of their equipment. However, the variety of work was limited on account of the expense and lack of facilities. Within the past few years, the reclamation of railway equipment has broadened into quite a wide field of application, largely through the development and practical application of electric arc welding. This method effects a great saving in making such repairs, as in many cases they can be made without dismantling, thus keeping the car in service, rather than having it standing idle in the shop for several days. Other advantages of this method of repairing are:—

1—Comparative low cost.
2—Ease and convenience of doing the work.
3—Speed of operation.
4—Reliability of results.
5—Saving of material.
6—Almost unlimited application.
7—Less skilled labor required.

APPLICATION

There is a wide range of application for electric welding in connection with the repair of railway equipment details but experience has shown that it requires a trained operator with good judgment to select the proper method of welding in order to secure the best possible results in each individual case. Any one method should not be condemned because of its failure to meet all requirements, as electric welding has its limitations and to get the best results, must be handled and applied intelligently. Some of the parts where electric welding may be used to advantage in the repair of the equipment are as follows:—

Truck frames	Flanges on worn car wheels
Brake hangers	Worn axles
Journal boxes	Worn journals on armature shafts
Gear cases	Broken and worn motor frames
Resistors	Axle brackets
Drawheads and under-framing	Damaged pinion fits of shafts
Worn dowel pin holes in axle bearings	Controller frames

In addition to the above, railway tracks can readily be repaired by building up material on cupped rails, worn frogs and cross-overs at points subjected to rapid local wearing, which are hammered by the wheels of the passing cars. It is also quite extensively used in rail bonding, where steel re-inforced bonds are used.

EQUIPMENT

The following equipment is necessary for an electric welding outfit:—

Welding booth.
Motor-generator set—preferably of portable type.
Electrode holders with cable.
Carbon and metal electrodes.
The operator should be supplied with the following:—
Helmet or shield
Gauntlets or gloves
Heavy shoes with tongues.
Leather apron.

METAL ELECTRODE WELDING

With this method, the operator uses a rod of low carbon steel as the negative terminal of the circuit to draw the arc, which fuses the metal from the metal electrode onto the work. This method is comparatively slow and uses a relatively small amount of power. The metal is deposited more uniformly and the weld is stronger and has a more regular appearance than when made with the carbon electrode method. Since the filler in this process is carried directly to the weld by the arc, it can be used on vertical surfaces and overhead work. For the above reasons, the metal electrode method is more generally used in connection with all-round repair work.

Operators—Experience has shown that a man with a slow steady easy-going manner can be trained to be a good welder within a month.

Preparation of the weld—The parts should be thoroughly cleaned, using a sand blast or a metal wire brush. If edges are to be welded, both should be beveled so that new metal can be deposited in the crack.

The Electrodes should be a high grade of low carbon steel wire, cut 14 to 18 in. long. Diameter of electrodes, from 1/16 to 3/16 in. depending upon the current values used which will vary from 50 to 225 amperes.

The Welding Current should be of such a value that the depth of the arc crater, or "bite", is not less than 1/16 in.

Arc Length—Preferably use an arc 1/16 to ⅛ in. in length as it gives better fusion, resulting in a more solid weld.

CARBON ELECTRODE WELDING

In this method the operator uses a rod of carbon as the negative terminal of the circuit to draw the arc, which fuses metal on the weld, from a filler rod held in the hand of the operator. This method is very rapid, but requires a comparatively large amount of power. The quality of the weld in the hands of the average operator is not quite so good as when made using the metallic electrode, and is not especially adapted to work where strength is of prime importance. However, this method is used to good advantage in the following applications:

1—Welding cast iron, cast steel, and non-ferrous, (copper, brass, etc.) metals.
2—Cutting of cast iron.
3—Rapid deposit of metal to build up surfaces where strength is of minor importance.
4—Melting and cutting up of scrap iron.
5—Remelting of surfaces to improve the appearance or fit.
6—Deposit of hard metal on wearing surfaces.
7—Cutting and welding of sheet metal.

Operator—Same as for "Metal Electrode Welding".

Preparation of Weld—Same as for "Metal Electrode Welding".

Electrodes—These were originally made of carbon, but recent experience shows that graphite has a longer life and makes a softer weld. These electrodes are from 8 to 12 in. long, tapered at one end, and vary in diameter from ¼ to 1.5 in. depending upon current values, which will vary with the work from 100 to 800 amperes.

Filler Material—Use commercially pure iron rods from ⅜ to ½ in. in diameter.

The Welding Currents used in this process are between 300 and 450 amperes. They may go as high as 600 to 800 amperes, depending upon the work and speed desired.

Arc Length—In general, too short an arc will deposit carbon in the weld, tending to harden it. Arc lengths will vary with the current. On the average, the arc should be from ½ to 1 in. with a 250 ampere circuit and ¾ to 1.5 in. with a 500 ampere circuit.

PRECAUTIONS

In connection with electric welding, the following points should be given special attention:

1—Connect the positive side of the circuit to the work.
2—Protect the eyes and body from the arc.
3—Have an ample length of flexible cable leads to allow free use of the electrode holder.
4—Thoroughly clean the surfaces to be welded.
5—Flux is not essential, but is a source of danger, as it may contaminate the weld.
6—Maintain a steady arc.
7—Heat cast iron before welding.

OXY-ACETYLENE WELDING

This method, commonly known as gas welding, is used very successfully, especially on small work and on non-ferrous metals. This process depends upon the heat produced by the combination of acetylene gas with oxygen in a common blow pipe or torch.

THERMIT WELDING

This method, which is primarily a casting process, is used mostly for repair work where considerable metal is required, as in the case of broken motor frames, heavy truck castings, etc. It depends on the chemical combination of aluminum filings mixed with oxide of iron which, when primed by a magnesium powder, generates an intense heat and fuses the metal into a molten mass.

JOHN S. DEAN

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

2042—RECONNECTING A DIRECT-CURRENT GENERATOR FOR HALF VOLTAGE AND DOUBLE CURRENT—A direct-current generator of 1.87 kw, 125 volts, 15 amperes, 1800 r. p. m. has been changed to one-half former voltage in the usual way by reconnecting the armature for double current and the four field poles with compound winding for one-half former voltage. What changes are necessary, if any, on commutator and brushes? There are 31 segments in the commutator, 4 brush holders and brushes. Size of brushes 7/8 in. by 1 1/4 in. Width of commutator bar 5/16 in. Length of bar or brush surface 1 11/16 inch. Circumference of commutator 10.5 in. It is desired to operate this generator at 40 amperes and 62.5 volts for 2.5 hours daily.

C. A. M. (WASH)

To change this machine over to a generator of one-half voltage and twice the current, the two-turn armature coils are opened on the commutator end and the two turns connected in parallel. The commutator bars will have to be re-slotted to take four wires per bar. The field coils should be connected in series-parallel. The cross-sectional area of the brushes will have to be approximately doubled. Since a brush now only covers three-fifths of a commutator bar, a brush of about 1 1/2 in. by 1/4 in. could be used, in order not to require a new commutator. Changing the size of the brushes necessitates new brush holders. Thirty amperes could be drawn from this machine after changing it over to half-voltage, with the same temperature rise as with the original rating. A machine of this size would in all probability have reached a constant temperature in 2.5 hours which means that a 2.5 hour rating is the same as a continuous rating. It is probable, however that on the basis of a 50 degrees C. rise, 35 amperes could be drawn from this machine.

H. S.

2043—CLEANING WATER COILS OF TRANSFORMER—We have in service six 500 kv-a oil-insulated, water-cooled transformers. These transformers have been in service for a number of years but we never experienced any trouble in keeping the water coils cleaned out, until recently the water was changed and the pipes were stopped up by a deposit of lime. The only way we were able to clean out these coils was to bore holes in a number of places and pour in muriatic acid. This method was successful in that it cleaned out the lime but it was very slow and it was necessary to repair the pipe wherever a hole was drilled. Please advise if you know of any better method for cleaning out these pipes.

J. O. P. (IND.)

Running a muriatic acid solution through a cooling coil is about the best known method of removing a coating of lime. If the cooling coil was entirely clogged up so that liquid could not be forced through, the method of getting the acid in was probably as good as could be devised. When a cooling coil begins to clog up it is indicated by a decreased flow of water and an increased temperature of the oil. When clogging is suspected, the matter should be looked into at once.

W. M. M.

2044—FREQUENCY AND POWER-FACTOR METERS—In calibrating both frequency and power-factor meters are they adjusted so as to return to some particular mark on the scale when the current carrying coils are on open circuit, or is the indicating needle supposed to stay at any particular place where it happens to be when the circuit is broken.

E. M. (N. Y.)

The indicating needle of frequency and power-factor meters is mounted on a shaft which carries the armature. As this armature is allowed to rotate freely in either direction in the more common types of meters it is obvious that the indicating needle, when perfectly balanced, will stop where it happens to be when the circuit is broken.

M. M. B.

2045—SPEED OF INDUCTION MOTOR—How many revolutions will a 25 cycle, three phase induction motor, rated at 20 hp, 450 r. p. m. make at 0, 1/4, 1/2, 3/4 load, if connected to a 30 cycle, three-phase, alternating-current circuit?

S. J. P. (MICH.)

It is impossible to make a definite reply to this question without knowing fully the operating characteristics of the motor, and specifically the speed torque of this particular motor. Certain general assumptions may, however, be made. If the voltage applied to the motor is increased in direct proportion to the increase in frequency, the operating characteristics of the motor will remain approximately the same, which will mean that you have the same percent slip at all loads that you had on 25 cycles and the speed of the motor will be increased 20 percent above its present value at all loads. If, however, the motor is operated on 30 cycles at the present voltage you will have the condition of a motor operating at 16.6 percent below normal voltage and under this condition the slip will be increased materially at all loads. On the basis that the 450 r. p. m. mentioned in the question is the speed at full load, it is evident that you have a six-pole motor operating normally at a high percent slip. As mentioned above it is impossible to calculate what the speed will be for the entire range of load under the new conditions but it is probable that at 30 cycles and rated voltage, the speeds will be of the general order of those given below: at zero load, quite close to synchronous speed or 600 r. p. m.; at one-fourth load, around 560 to 570 r. p. m.; at one-half load, around 530 to 540 r. p. m.; at three-fourths load, around 475 r. p. m.; at full load, around 450 r. p. m.

C. R. R.

2046—COMPRESSOR CAUSING FLUCTUATIONS IN CURRENT SUPPLY—We are manufacturers of CO_2 refrigerating machines. At present we have a contract to install an 80 ton machine for the purpose of cooling air in a theater. Heretofore, on large compressors operating in moving picture theaters considerable trouble has been experienced with the projection machine, due to fluctuations in the current caused by the compressor strokes. Now we are trying to remedy this matter by using the proper flywheel, and before we go very far in our calculations we would like some comprehensive data regarding the calculations of flywheel weights for such applications, as a basis for this and future installations. Therefore we will be greatly obliged if you can furnish us with such data covering both belt drive with an induction motor; also with synchronous, the synchronous motor to be either belt or direct connected, although we feel that direct connection in this case would be impractical, as the compressor speed is only 90 r. p. m. The dimensions of the compressor are as follows:—bore 6-5/8 inch, stroke 24 inch, discharge pressure 60 atmospheres, suction pressure 22 atmospheres. All information that you can give us regarding the proper flywheel for belt drive or synchronous motor for direct drive will be greatly appreciated.

E. J. I. (ILL.)

This is a question that cannot be given a definite answer. In the first place we do not know how much current fluctuation can be tolerated. If this were known the required flywheel effect could be calculated with a fair degree of accuracy for a direct-connected unit. For a belted unit there is a damping effect due to the belt which should make conditions better than calculations indicate. The method of treating this problem when synchronous motors are used, assuming, of course, that the permissible current fluctuation is known, is covered in an article published in the JOURNAL for January 1920. In this article the limit of angular variation is set at three electrical degrees which means about five to ten percent periodic change in current. The change in line voltage which accompanies a given current fluctuation is governed entirely by the power supply so that a unit which gives no trouble in one installation will not necessarily be satisfactory in another. If experience shows that the flywheel effect required is excessive it would probably be well to consider supplying the projection machine from a motor-generator set. Also would suggest that this trouble could be avoided by building compressors having the proper number of cylinders driven from a crank shaft thus obtaining an almost uniform load. It has been found that two or three single cylinder compressors units, when operated at the same time, cause less trouble than when one unit is operated alone.

Q. G. & M. M. B.

47-5

The Electric Journal

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Electricity in the Textile Industry

The application of mechanical power to the manufacture of textiles, which formed the beginning of the textile industry was developed in the last half of the eighteenth century in England, when power machinery for the production of textiles was invented. These ideas were first incorporated in this country in a cotton mill started at Pawtucket, Rhode Island in 1790. The growth of this industry has been rapid and at the end of 1919 there were 6521 establishments whose total value of product amounted to $5 127 000 000 annually. Cotton, wool, silk, jute, flax and other fibres are woven, knitted and finished in great variety of forms, not only for clothing, floor coverings and other domestic purposes, but for belting, tire fabric, artificial leather, automobile tops, insulating materials, etc.

For many years the water wheel was the prime mover used; later, the steam engine came into extensive use. In either case the prime mover supplied power to a main line shaft from which it was transmitted to the various machines by means of shafts, ropes and belts. While it would be expected, with a power transmission system of this kind, that the friction losses would be considerable, and the speed regulation not all that could be desired; nevertheless, in many of the mills were to be found power transmission systems which were a credit to the engineering ability and ingenuity of those responsible for the installation.

In this industry the question of speed regulation is most vital, as upon it depends the quality of the finished material. Moreover, by operating the machines at the highest permissible speed, the maximum production is obtained. Therefore, any motive power that would operate the machines at a constant speed is greatly to be desired. While an approach to this condition could have been made by the substitution of a number of prime movers, each to drive smaller groups of machines, such a scheme is impractical, from an operating and economy standpoint, for any but electric drive.

While the introduction of electricity in the form of direct-current would have permitted a more economical method of transmitting power as compared to mechanical drive, the use of a direct-current motor was given very little consideration on account of the fire hazard.

The alternating-current system affords an excellent method of transmitting power, while the squirrel-cage induction motor has the proper speed-torque characteristics and, in addition, eliminates the fire hazard. The first squirrel-cage induction motors were installed to drive groups of machinery in plant additions where the prime mover had insufficient capacity to take care of the added load, or were used to replace prime movers, where the latter had outlived their usefulness. From an operating standpoint induction motors were highly satisfactory and in a short time were firmly established. It was soon discovered that the machines driven by the motors had fewer broken ends, due to the more nearly constant speed at which they operated; furthermore, that increased production was being obtained on account of the fact that the speed of the machine was higher than the average of the speed on the machines that were mechanically driven from the prime mover. This led to the use of additional motors and separating the machines into smaller groups, which gave material reduction in the friction losses and at the same time improved the operating conditions.

With each sub-division in the grouping of the machines, thereby making use of smaller motors, it was natural that attention should be given to the operating characteristics of the various machines with a view to applying an individual motor to each machine. This work has been carried on over a number of years, until at the present time a satisfactory individual motor drive has been applied to a large portion of the machines used in this industry.

The increase in electric textile drives has been very rapid, as shown by the following tabulation:—

	1899	1904	1909	1914	1919	1924 Est.
Total Hp.	1 300 000	1 600 000	2 000 000	2 470 000	2 980 000	3 500 000
Electric Hp.	50 000	160 000	420 000	840 000	1 440 000	2 200 000

All new mills are laid out with the idea of using the latest type of electric drive and each year a number of mechanically-driven mills are changed over to electric drive. The electric drives are increasing at a much higher rate than the total horse-power, indicating the gradual elimination of all other forms of drive. This extensive growth has been due to the recognized superiority of motor drive over other forms and to the rapid growth of the central stations.

Instead of seeing new power houses built in connection with the new mills, it is now a familiar sight to see a small substation in which is installed the necessary transformers and switching equipment to distribute the power from the power company's lines.

In the finishing end of this industry, where it is necessary to have adjustable speed on a number of the machines, the direct-current motor is used quite largely. In the past few years, some very extensive improvements have been made in the driving of machines in finishing plants which have shown quite a saving over previous methods of drive.

The design of electrical equipment for the textile

industry has been given very careful consideration by the leading manufacturers, as it was found that conditions in this industry were different from those found in other industries and that special features were necessary in order to have the equipment give good operating service. J. R. Olnhausen

Electrification of New England Textile Mills

The textile industry is the largest and one of the oldest industries in New England. There are over twelve hundred establishments representing all the subdivisions of the industry, i.e. mills for cotton, wool, worsted, silk and other fibres and the finishing of the final product. The total horse-power involved to operate these mills is in excess of a million and a quarter, and the rate of increase during the past fifteen years has been approximately four percent. At the present time over one-fifth of this power has its source in water wheels located on the mill properties, about three-fifths is generated by steam by the mills themselves, and about one-fifth is purchased from the central power companies. About 50 percent of the power is transmitted electrically.

The tendencies in connection with the generation and distribution of power have been:—

1—To redevelop existing water powers.
2—To purchase central station energy.
3—To use motors direct connected to the individual machines.

These tendencies have been very largely accelerated by higher prices of fuel material and labor.

Water power determined the location of the older mills. Many of these mills still have wheels of old design now operating at an efficiency of 60 to 70 percent and with a capacity to handle the stream flow from eight to nine months of the year. With coal at the present prices the saving to be effected with modern wheels with an efficiency of 85 to 90 percent and a capacity to handle the stream flow for ten to eleven months almost invariably justifies a redevelopment on this basis alone, without regard to the advantages incident to the rearrangement of control and electric transmission.

The connected load of the central power stations in New England has been increasing at the rate of nearly 100 000 hp per year and a substantial part of this is represented by the textile industry. New mills without use for low-pressure steam in the process or for heating, or where the steam requirements do not synchronize with the load, almost invariably purchase their power where it is available. The elimination of the investment for power plant, the location of the plant without respect to condenser water, the avoidance of difficulty in the securing of fuel and labor are often among the considerations influencing the purchase of power.

In the older mills, with existing engine and boiler plants, the purchase of power is often brought about by the condition of this equipment. Sooner or later the management is confronted with the problem of renewing the prime movers or boilers or both, or providing some other source of power. It often develops that the initial cost of electrification exceeds by little the cost of new boilers and their installation alone, and that power can be purchased at a cost not exceeding the cost of operating a renewed plant. In this event the decision is in favor of the purchase of power, which also secures the advantages of electric transmission.

The original installations of electric transmission involved large motors and the elimination of the largest belts and headshafts only, leaving the shafting and belts and providing but few sources of constant speed (the motors) instead of one (the engine.) It is now very generally recognized that the proper arrangement of motor drive is to put the motor on the driven machine itself, so far as this is practical, eliminating mechanical transmission and providing a source of constant speed at every machine. Motors on the machines themselves may also be provided with characteristics that can not be readily provided mechanically, such as automatic acceleration and deceleration between pre-determined speeds or control remote from the drive and convenient for the operator.

Some interesting tests were recently made in four different and well conducted mills to determine the relative variation in the front roll speed of spinning frames driven by three different methods, mechanical, four frame and individual drive. In each of the mills the tests were made in a single row of frames across the mills and the results obtained in each mill were approximately the same as secured in each of the others. With mechanical drive the average variation in speed from the highest speed to the lowest was in excess of six percent and no data was secured to determine whether the machine at the highest speed was running too low. With four frame drive the variation in speed was in excess of two percent. With individual drive there was, of course, no variation.

The idea of using individual motor drive to provide a source of constant speed at the producing machines themselves has been very largely carried out in the new mills recently built in New England. Shafting hangers and belts have largely disappeared, and the average horse-power is about 1.5 in one of these new cotton cloth mills.

While the use of individual drive cannot be so largely undertaken in electrifying an existing mill, the tendency is the same i.e. to get the source of constant speed as close as possible to the driven machine. The use of individual drives in these mills often comes about when the old machines are replaced with new, or additional machines are installed.

G. D. Bowne, Jr.

The Central Station and the Textile Mill

F. S. ROOT

NO textile manufacturing plant would be built to-day for anything but electric drive. One cannot be so positive in asserting that such an electrically equipped mill would invariably purchase its energy from the central station. Nevertheless, we firmly believe that in the very near future, no textile mill, new or old, will any more think of making its own power than it would of making its own looms. We base this belief on the only means of judging the future, that is on events of the past.

In any change in industrial methods, it is safe to consider that whatever is adopted as good practice by the most conservative section of the country, will certainly be followed, (and generally anticipated) by the rest of the country. New England is admittedly more conservative as regards changes and innovations in methods of textile manufacturing than is the South and, therefore, we will confine our study to one city only, noted for its conservatism along textile lines; assuming that anything meeting with ready acceptance in its textile plants, would not be too radical for any other section of the country.

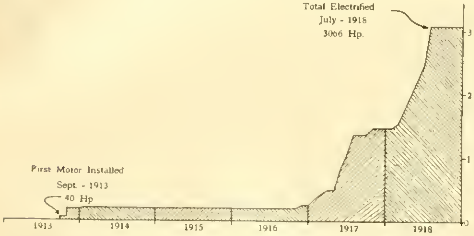

FIG. 1—THE INTRODUCTION OF CENTRAL STATION SERVICE INTO MILL C

Up to 1911, there were over one hundred cotton mills in the town, only one or two of which were electrically equipped, and none buying energy of the central station, except in a few cases where a machine shop or an elevator might have had a motor put in to be used for overtime or emergencies. In 1911 a new mill was erected, of 50 000 spindle capacity, requiring 1500 horse-power in motors and designed solely for the use of purchased power. Despite the head shakings of the owners of the mechanically driven mills, this plant, "Mill A," was a success from every angle. It was, (and still is) an ideal customer from the central station's viewpoint, since both its power-factor and load factor are very high, and about one-third of the energy purchased is used for night-time running. At the present time this mill has 2000 horse-power connected to the central station's lines and uses, during normal business conditions, over 400 000 kw hrs. per month with a demand of but 1350 kw.

About the same time that this mill was erected, a new narrow fabric factory, also designed for central station service, was put up, requiring about 300 horse-power. This venture has also met with success and has grown to over 400 horse-power capacity.

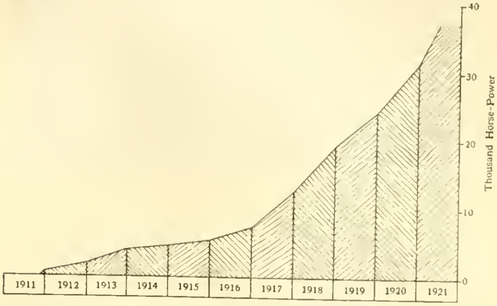

FIG. 2—GROWTH OF CENTRAL STATION SERVICE IN LOCAL TEXTILE PLANTS

The first mill to be changed from mechanical to electric drive (Mill C) was an old mill, incorporated in 1874. Power was furnished by two cross-compound Corliss-type engines rated at 3300 hp, and up to the latter part of 1913, no electrical energy had been purchased. In September, 1913, a radical change in the styles of goods produced was made, resulting in an unbalanced load in different departments. To correct this it was decided to install motors operated by the central station on some of the twisters and ring spinning frames for overtime use only, and a 15 hp

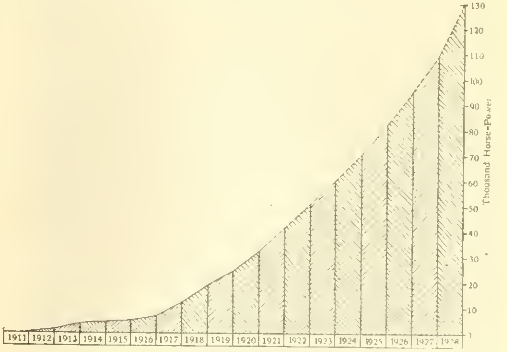

FIG. 3—PREDICTED FUTURE GROWTH OF THE USE OF CENTRAL STATION POWER IN LOCAL TEXTILE PLANTS

and a 25 hp motor were used to drive nine twisters, while two 75 hp motors were installed on a group of twenty-four spinning frames and slubbers.

For three years no more power was purchased, although the motors which were installed were inter-

mittently used and were sometimes moved to other groups of machines which had fallen behind in production. Then, in the last months of 1916, war orders began to come in and profiting by past experiences, this mill began to install more and more motors and to operate considerable of its machinery all night.

FIG. 4 TECUMSEH SUBSTATION

At the end of 1917 about half the mill could be driven by motors, which were operated at night through positive jaw clutches, the machines driven by them being carried on the steam drive during the day At about this time some of the boilers began to show signs of weakness and it was decided to relieve them and the engines also, of a large part of the load by operating all motors all the time. The saving possible by complete electrification of the whole mill then became very apparent and before the end of 1918, both engines were permanently shut down. This mill now uses about 550 000 kw-hrs. per month and has 3638 hp installed. Fig. 1 shows graphically the progress of electrification of this mill.

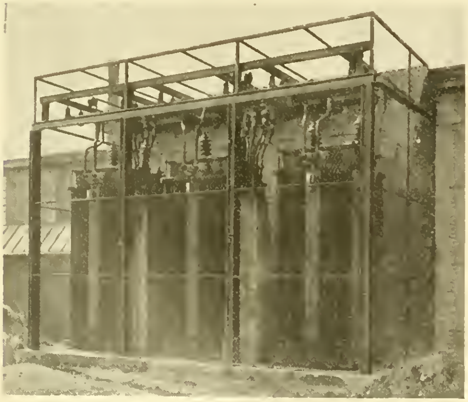

FIG. 5—THREE 333 KV-A, 23000-550 VOLT TRANSFORMERS IN SHAWMUT SUBSTATION

The use of central station service in other mills also took added impetus, due to war orders, and from the few motors installed for overtime work, complete electrification followed after the war in several cases. There are now seventeen textile plants in this city completely electrified, totalling 21 470 horse-power, and twenty-six others, each of which have from 100 to 1500 hp of purchased power installed, totalling 12 910 hp. All of the remaining mills, except two, use some central station energy.

The growth in this city of purchased power for textile use since 1911 is shown in Fig. 2. The most

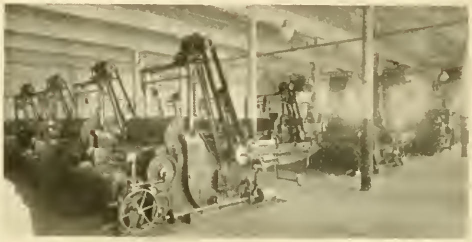

FIG. 6—MOTOR DRIVEN PICKERS

important point to be noted in connection with this growth is the fact that once obtained, it is never lost but, on the other hand, gathers volume at a rapidly increasing rate.

There is about 130 000 horse-power in textile plants in the city under consideration. Basing future performances on past history, we can, from the curve given in Fig. 2, plot the curve shown in Fig. 3, which would seem to indicate that within seven years, every mill in the city will be operating entirely on central station power. This condition will probably fall a little short of realization, partly due to the fact that the central station itself will probably be unable to take on so much business so rapidly, and partly to the fact that some of the mills will pass through an intermediary step before using purchased power, i. e., some of

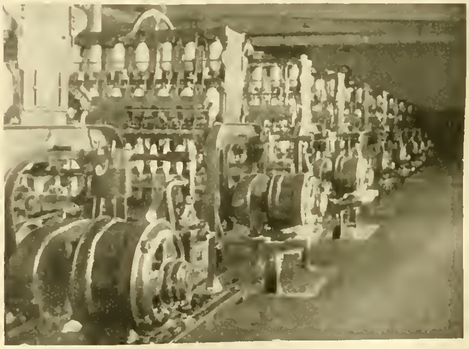

FIG. 7—MOTOR DRIVEN SPINNING FRAMES

the plants may put in low-pressure turbo-generators and partly electrify, thus postponing complete electrification from the central station for several years.

Although it is not the intention to take up motor applications to textile work, a few pictures will illustrate the conditions under which central station

service in the city is rendered. Energy is sold at 23 000 volts, requiring a substantial substation which is furnished by the customer. Some of these have been very elaborate and have cost nearly $30 000 to erect. Others have been just as good, though less pretentious. Fig. 4 shows such a sub-station which utilized in part two retaining walls of the former coal pocket as two sides to the substation. In this case the transformers were housed within the building. Fig. 5 shows another and smaller substation in which the transformers were placed outside the substation. Both methods have been perfectly satisfactory.

The method used in driving pickers by individual motors, Fig. 6, is introduced for three reasons. First, the well-known one of the freeing of the picker-room ceiling of all overhead shafting; second, the neat way in which these motors are wired up (see conduit following up the groove of the "A" frame); and, third, because of the type of lighting used. The individual, direct-connected motor-drives on the spinning frames shown in Fig. 7, are happily becoming common practice in many cases and need no comment.

The growth of the use of central station service in textile plants has been very rapid in the past five years but we firmly believe that it is, after all, only a beginning, and that the next five years' growth will only be limited by the central station's ability to take care of it.

Modernized Plant of Prudential Worsted Co.

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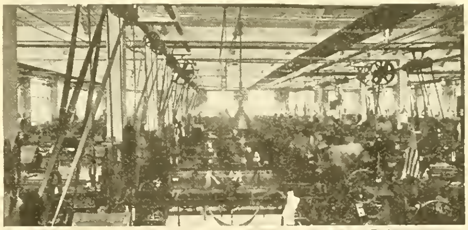
Anticipating the keen competition which was sure to come with the return of the textile business to a normal basis, The Prudential Worsted Company decided during 1919, thoroughly to modernize their plant at Philadelphia. The plant was originally operated from a steam engine drive, the power being transmitted through a series of shafts and belting to the various floors where it was distributed by belts to the machines.

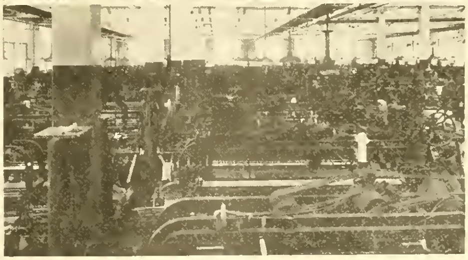
First a detailed study was made of the processes, and accurate power and speed tests were made on each machine. In the weave shed, there was a main line shaft in the center running the length of the room with belts running to countershafts on each side of the main shaft. Due to the non-uniformity of belt tension on all the drives, a variation of six to eight picks per minute was found to exist between the looms operating from the countershafts and those running from the main shaft. This clearly represented a loss in production.

Modern mill operation unquestionably demands that the power applied to a machine must have a constant speed, both instantaneous and continuous, and the machine in each case for maximum production must operate at the highest speed consistent with the quality of work and the ability of the machine operator.

This lead to the consideration of individualizing each machine with a separate motor, for only in this way could the elimination of speed variation be accomplished and, in addition, many other advantages be obtained, such as elimination of overhead shafting, belting, belt guards, etc. Constant speed on the looms naturally increases the total power consumed by the looms over that previously used, but this was more than balanced by the elimination of the friction load and increased production.

In analyzing the power requirements for the weave rooms, there were many factors to be considered. For instance, when a belt driving a loom from an overhead shafting becomes loose, the loom bangs off more frequently and sometimes causes the shuttle to fly out, making it dangerous for the weaver, beside breaking out warp ends which represents a loss of production. Also due to irregular speeds caused by





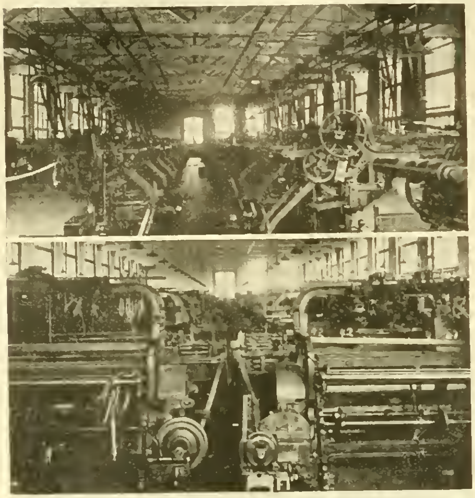
FIGS. 1 AND 2—VIEWS OF WEAVE ROOM BEFORE AND AFTER INDIVIDUAL MOTORS WERE INSTALLED

loose belts, trouble is experienced by cops knocking off in the shuttle. Now, consider each loom equipped with a waste packed bearing motor, the upkeep on which includes the time for oiling which is once every three months, and compare this with the amount of time consumed in a belt driven plant, in oiling loose pulleys, cleaning and cutting belts, replacing burned-out bear-

ings due to tight belts, replacing pulley bushings worn out due to insufficient oil and many other odd jobs that are always coming up with the belt drives.

Views of one of the weave rooms before and after it was equipped with individual motors are shown in Figs. 1 and 2. The weave room on the third floor was similarly equipped, but the looms in this room were all rearranged so as to provide for wider aisle spaces and also additional machinery, as shown in Figs. 3 and 4.

In the winding room it was found that the power requirement for the machines themselves was so small as compared with the total power required for the shafting and the load that, for economy, each machine was equipped with a small motor so that energy was being consumed only when a given machine was actually in operation.



FIGS. 3 AND 4—WEAVE ROOM BEFORE AND AFTER THE LOOMS WERE REARRANGED AND EQUIPPED WITH INDIVIDUAL MOTORS

In the warping and sizing room, a similar condition existed. Here there are two distinct operations; first, the yarn is dressed or sized by running it through a starch mangle, over a small set of dry cans to a large cylindrical frame from which the yarn is later beamed off by the same operator on to a beam ready for the looms. The dressing machine is operated from a separate motor which is closed down during the beaming off process, which is also done from a separate motor and this latter motor is closed down during the former process. Two motors were used for the warp dresser because if only one motor was used and of sufficient size to operate the beamer, which requires the greater load of the two and is operated only a short time out of the total, then when this motor was running the dressing machine, it would be carrying only about 1/8 load. For a one motor drive, line shafting and belting would also be required with the necessary belt guards.

In this way all line shafting was eliminated, with the consequent advantages of an economical and extremely flexible plant. For instance, when it is necessary to operate some sample looms or any one department overtime, it can be done independently of the rest of the mill.

The Prudential Worsted Company have been running continuously on the electric power for the past two years, during which time a careful record has been made of the increased production and a close analysis made of the advantages gained by utilizing the modern method of driving textile machinery, a few of which are outlined below:—

FIG 5—INDIVIDUAL MOTOR DRIVE ON SPOOLERS

1—Five percent increased production, resulting in a decreased overhead charge for a given output.
2—Twenty percent less loom breakage and consequently less work for the loom fixers. This means less maintenance and fewer looms idle due to mechanical troubles.
3—Elimination of loss of time due to tightening belts and maintaining belt guards.
4—Elimination of shuttle flyouts, due to irregular speeds, resulting in making it safer for the weaver, all of which means increased production.
5—Saving in cost of rebabbitting bearings on the loom countershafts and in time for changing the speed of the looms. The old way to change the speed of a loom was to remove the loom countershaft and change the gearing. The new way is to loosen four bolts in the motor base and change the motor pinion.
6—The utmost freedom regarding arrangement of machinery and the ability to operate these machines independently of the rest.
7—Extensions and additions are greatly facilitated.

The Textile Industry in the South

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THE textile industry in the South is confined entirely to the manufacture of cotton products, i.e., duck, sheetings, print cloths, colored goods, tire fabric and numerous yarns. The natural advantages of the Southern states as a cotton manufacturing centre have impressed capital more and more, with the result that since 1900 the majority of the new cotton spindles installed in the United States have been in this district. In 1900 there were approximately 2 000 000 cotton spindles in the South. At the present time approximately 16 000 000 spindles are installed, which is at the rate of 650 000 spindles per year for the past twenty years.

The first mill to be equipped with electric motor drive was put in operation during 1894 in Columbia, S. C. In 1904 about five percent of the total horse-

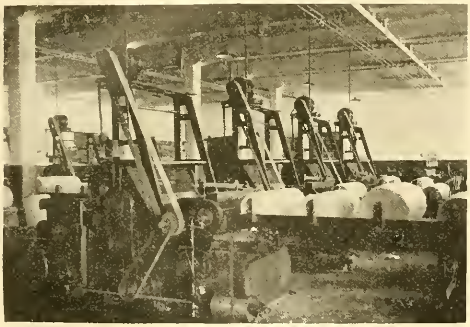

FIG. 1—INDIVIDUAL MOTOR DRIVE ON INTERMEDIATE PICKERS

power installed was electric. The advent of the induction motor and the activities of the hydroelectric power companies gave an impetus to the electrification of these mills, and at the present time fifty percent of the total installed horse-power is electrified.

The South has been very partial to electric drive and has been willing to accept readily the new types of drive as they have been advocated. Since the bringing out of the individual motor drive for various machines in this industry, the greatest percentage of such drives have been installed in southern mills. At present the individual drive is used extensively on new electrifications, and in addition, a large number of mills are superseding their present group drives with individual motors. In 1912 the average size of motor used was 50 hp. This has decreased to 4 hp in 1919 and it is estimated that for the year 1922, this will be further reduced to 3 hp, thus showing the extent to which the South has gone to individual motor drive.

The typical southern mill carries on the following operations in the manufacturing of their product:—

1—Picking.
2—Carding.
3—Combing.
4—Spinning and twisting.
5—Weaving.
6—Finishing.

PICKING

Before the cotton can be spun it is necessary to break the bales, remove the coarser impurities and eliminate all tangles and trash. The process of picking consists of opening, breaking, and passing the cotton through the intermediate and finisher pickers, each putting the cotton fibre in better shape. It is delivered from the picker in the form of a wide roll of cotton batting known as "lap".

For many years the advantages of individual motor drive for the picking room have been recognized and practically no mills in recent years have installed

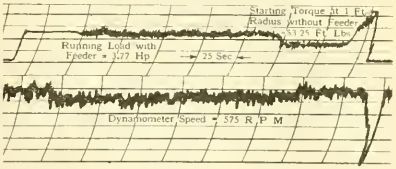

FIG. 2—TYPICAL POWER CURVE OF A BREAKING PICKER

any other form of drive. The motor is mounted on the A-frame which is supplied by the manufacturer and is belted to the beater shaft. In the case of a double beater picker, it is necessary to drive from each side, so that a double extended shaft motor with an outboard bearing must be used, as the distance between centers of pulleys varies from six to seven feet. Lately two-motor drive has been used on the two-beater pickers with good results, the motor being mounted on each end of the A-frame and driving to the beater shaft. This makes a better mechanical drive and the cost is very little greater than the larger motor with the special shaft and outboard bearing.

CARDING

From the picker room the lap goes to a revolving flat-type of card whose function is to straighten the cotton fibres still further and remove all the short length fibres, and any impurities or trash. The fibres are straightened out by combing them with wire brushes or cards. The cotton comes from the cards in the form of a soft roping known as "sliver" about ¾ in. in diameter. In the past, group drive has been used in the driving of cards. Common practice is to

mount a 15 to 50 hp motor on the ceiling to drive a line shaft from which the cards are driven. There has recently been developed, however, an individual drive for cotton cards, which takes care of the stripping and grinding very satisfactorily and in addition, permits the starting of a card without putting on a

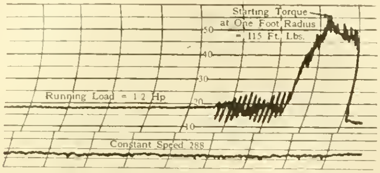

FIG. 3—TYPICAL POWER CURVE OF A REVOLVING FLAT CARD

motor several times too large, due to the high torque required at start.

COMBING AND ROVING

In mills for fine yarn, or where coarse yarns of special grades are to be made, the cotton must be further treated with a combing process. The sliver goes through a lap machine, reducing the sliver to a lap

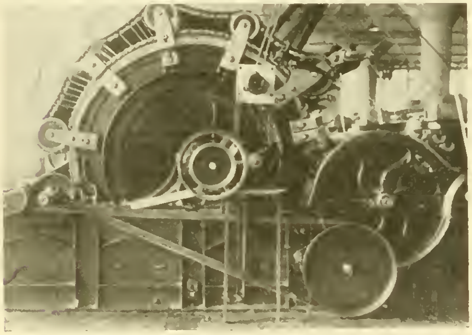

FIG. 4—INDIVIDUAL MOTOR DRIVE ON REVOLVING FLAT CARD

about a foot wide. This drawing process is further to straighten the fibre. The lap then goes through the combers, which actually fine-tooth combs the cotton lap. Six or eight laps going through the machine at once are combined, condensed and formed again into a continuous sliver. The processes above are sometimes called "drawing" and consist of a continual lengthening and straightening of the lap of sliver as it goes through each machine. Just how often this operation is performed depends upon the grade of yarn to be made.

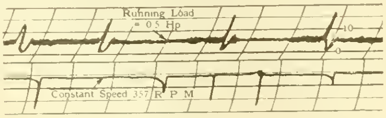

FIG. 5—TYPICAL POWER CURVE OF A COMBER

In the process of roving, the cotton is put through slubbers, intermediate frames, fine and jack frames. From the drawing frame the sliver passes to the slubber, which continues the drawing and puts some twist in the cotton, and for the first time puts it upon a

FIG. 6—THE TWO AND FOUR-FRAME METHOD OF DRIVE ON ROVING FRAMES

spindle. From the slubber it goes to the intermediate frames, then to the fine frame and then to the jack frame, all of which combine two or more cotton strands by twisting and drawing.

Individual motor drive has been worked out for the majority of these machines experimentally and the results have been very gratifying, so that within a short time this type of drive will be used extensively. The majority of the installations at the present time use either the group drive or else the two or four-frame drives.

SPINNING AND TWISTING

The cotton taken from the jacks or fine frame is put through a process of spinning which turns the

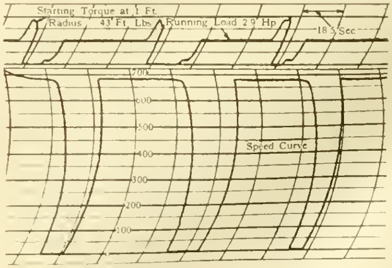

FIG. 7—TYPICAL POWER CURVE OF A SPINNING FRAME

cotton into firm yarn, sufficiently twisted and strong, ready for the looms. Practically all the spinning in the South is what is known as ring spinning. The spinning is a continuous process and the output depends largely on maintained speed. The horse-power for spinning represents about 50 percent of the total

in the mill and naturally has come into the greatest consideration for individual drive. Individual chain motor drive has come into wide use through a general acceptance of its distinct advantages over any other form of drive. The loss in production due to belt slippage is entirely eliminated. Belted applications re-

FIG. 8—INDIVIDUAL MOTOR DRIVE ON SPINNING FRAMES

quire a vertical belt drive of anywhere from 25 to 30 feet and a small amount of belt stretch results in loss of speed and consequent loss of production. The silent chain individual motor drive gives flexibility, as changes in number of yarns can be made by changing motor sprockets. Chain drive makes motors of standard torque characteristics ideally adapted to this service. The individual spinning drive was bought out in Southern mills and practically all new mills are being equipped with it.

The twisting process consists of taking two or more yarns after it comes from the spinning frame and has been spooled, and twisting them into a single yarn. The enormous demand for automobile tire fabrics has largely increased the number of twisters in

FIG. 9—INDIVIDUAL MOTOR CHAIN DRIVE ON TWISTER FRAMES

use. Individual motor drive has been applied to twisters in a similar manner to that of spinning and is the most popular drive in use at the present time.

WEAVING

To prepare the threads for weaving, on the loom, it is necessary to put the yarn through a process of spooling, warping, sizing and slashing. The thread is wound from the spindles onto spools, from which it is wound on the beam by the warper, and then passes to the slasher, where the sizing is put on, then to the loom. The spoolers, warpers and slashers are individually driven.

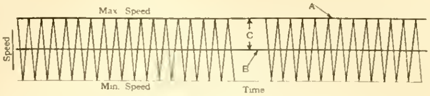

FIG. 10—TYPICAL SPEED TIME CHART

Of an individual motor-driven, geared, automatic loom compared with a belt drive unit.

The majority of the new looms are individually motor driven, thus eliminating all belts in the weaving

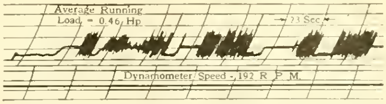

FIG. 11—TYPICAL POWER CURVE OF THE COTTON LOOM

plant. This drive gives a higher average speed, resulting in increased production. It also reduces loom fixing and gives a more uniform speed and a better quality of finished goods.

A typical speed time chart of an individual motor-driven geared automatic loom compared with a belt driven unit is shown in Fig. 10. With the belted loom the speed is varying, due to belt slippage and the peak power requirements of the loom. The average speed obtained is considerably lower than the maximum speed at which the loom can be operated on account of the above variations. The varying speed produces a poorer cloth, less yardage and causes more loom fixing. The geared motor drive enables the manufacturer to operate the loom at a more constant speed and

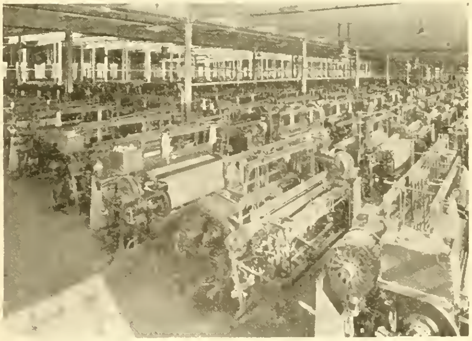

FIG. 12—INSTALLATION OF INDIVIDUAL MOTOR-DRIVEN LOOMS

nearer the maximum that the loom will stand.

FINISHING

The process of finishing includes bleaching, dyeing, mercerizing and printing, but only a small percentage of the total spindles in the South do this work, the principal output being unbleached sheetings and yarn.

TABLE I—POWER REQUIRED BY TEXTILE MACHINERY

MACHINE	Horse-Power
Single beater opener	5
Two-beater opener	7.5
Two-beater opener with single hopper feeder and cage section	10
Trunking opener with double hopper feeder	7.5
Two beater roving, waste opener	7.5
Single beater breaker with or without single hopper feeder	5
Single beater breaker with condenser section	7.5
Single beater breaker with double hopper feeder regulator	7.5
Two beater breaker with condenser section	10
Two beater breaker with feeder	10
Single beater intermediate or finisher lapper	5
Two beater intermediate or finisher lapper	10
Revolving flat card production 350 lbs per week	0.75
Revolving flat card production 750 lbs. per week	1
Revolving flat card production 1000 lbs. per week	1.25
Drawing frames—6 deliveries per hp.	1
Sliver lap machines	0.5
Ribbon lap machines	1
Combers—8 head-running—130 single nips per minute	0.75
Combers—8 head-running—130 double nips per minute	1
Slubbers—45 spindles per hp.	1
Intermediates—55 spindles per hp.	1
Roving frames—65 spindles per hp.	1
Fine or jack frames—70 spindles per hp.	1
Spinning frames—filling yarns	5
Spinning frames—warp yarns	7.5
Twisting frames	7.5 to 10
Beam twisting frames for tire fabric yarns	10 to 15
Mule spinning frame 90 to 100 spindles per hp.	1
Spoolers—200 spindles per hp.	1
Cone winder	5
Beam warper	0.75
Ball warper	1
Slasher including fan	5
Looms up to 40 inch width	0.5
Looms up to 90 inch width	0.75
Looms above 90 inch excepting tire fabric	1
Tire fabric looms	2
Trimmers	2
Folders	0.5
Cloth baling press—50 ton pressure	7.5

The mills that do their finishing usually arrange the motors in groups, but undoubtedly more of this finishing work will be done in the South, in which case the individual applications that now predominate in other districts will be used.

Table I gives a summary of the various machines used, with their power requirements. These figures are based largely on the use of individual motor drive.

The mills are rapidly extending their electrifications to new fields and improving their present electrification. Many motor drives are being subdivided and rearranged to get more efficient drives and better output. A great deal of attention is now being paid by engineers to the correct system of lighting and vast improvements have been made in this direction, the mills superseding their old lighting systems with up-to-date illumination. Within the past year, actual figures from a cotton mill in Canada shows that electric heating can be installed and operated as economically as a low-pressure steam heating system. Work is being done towards electric heating on slashers, tenters, etc. and it can reasonably be expected that in the near future electricity will eliminate the boilers that are now used to produce the steam required for heating purposes.

The Design of Induction Motors for Textile Service

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IN THE earlier developments of electrical drive for textile mills, the steam engine or water turbine was replaced by a large electric motor, which was belted to the line shafting driving the entire mill. The motor was installed in what was previously the engine room, where operating conditions could be made to suit the motor and therefore a motor of standard design and construction was used. These applications offered no special problems. It is interesting to note how the special features of motor design have developed as the motor drive has passed through the different stages from the large motor driving the entire mill to the present day practice of a motor for each individual machine.

As the electrification of the textile mills was not attempted to any extent until after the introduction of the polyphase system and the induction motor, polyphase current has been almost universally used in the textile industry, except in the finishing and printing plants. Constant speed is required by most of the machinery in the mill and no motor meets this requirement better than the squirrel-cage induction motor. Its simplicity of construction and operation peculiarly adapts this motor to textile service; the absence of sliding contacts is highly desirable in a mill where the atmosphere is laden with inflammable lint.

The textile mill covers a large amount of floor space and therefore requires long line shafting and numerous belts when one driving unit is used; so that it was natural that the textile mill operators early appreciated the advantages of the transmission of power by electric wiring, and soon replaced the large motor by a number of smaller motors driving groups of machines in the different departments, thus not only reducing the line shafting but also obtaining independence of operation in each department. It soon developed that motors of standard design would not meet the operating conditions and the two troublesome factors first encountered were lint and humidity, the first a natural by-product of the processes and the second a necessary condition for the proper working of the textiles. The lint consists of small cotton or woolen fibres thrown from the materials as they are worked through the different processes, and is held in suspension in large quantities in the air in the mill. The lint is carried by the air currents and not only finds its way through every crevice, but is deposited on all rough surfaces. This lint is drawn into the motors by the

ventilating air and, clings to the windings and rough surfaces and, where the air passages are small, in a short time clogs the ventilating system, causing the motors to overheat. Fortunately the motors used in group drive are large, ranging in sizes from 50 to 150 hp, and therefore have large and accessible air passages that do not clog quickly with the lint and can easily be cleaned. These troubles from lint then are not so serious in the large motors but have resulted in the use of liberally rated motors rather than in means of excluding the lint.

The lint makes trouble in another way, by working its way into the bearing housings of the motor and interfering with the oiling system. In motors of this size, it is necessary to use bearings of the ring oiling type and the lint not only clogs the oil grooves and drains, but in many cases prevents the turning of the oil rings. Further, it forms in streamers that dip into the oil and hang from the openings in the housing; these act like wicks to syphon the oil from the reservoir. Dripping oil is not only very undesirable in a mill handling fine textiles but, together with a clogged oiling system, results in too frequent oiling or burnt out bearings. To meet this condition the dust proof bearing has been developed. In this type of bearing all openings and joints are sealed with felt gaskets; a felt pad is placed under the oil hole cover and felt gaskets reinforced with steel washers are attached to the ends of the housing fitting snugly around the shaft. The overflow plug, which maintains the oil level at the proper height in the reservoir, is provided with an overhanging hinged cover with a clearance that is sufficient to allow the oil to overflow, but yet small enough that, with the overhanging feature, the lint cannot reach the oil chamber. The opening in the overflow is made large to permit the filling of the bearing through it so that it is not necessary to open the oil hole cover in the top of the bearing housing except for inspection.

The humidity in the mill is maintained at a constant value by artificial humidifiers and this moisture finds its way into the insulation of the motor windings. The voltage almost universally used in textile mills is 550 volts, the highest permissible with so-called low-voltage motors. The standard insulation is working up near the limit for which it is designed, and any deterioration in its insulating qualities due to moisture soon results in a failure. The effect of the humidity is not so serious when the motors are running, as the heat produced in them prevents the penetration of the moisture into the windings; but when the motors are shut down for a sufficient period to allow them to cool off, as is the case over night or Sunday, the moisture penetrates the insulation. Experience has shown that with motors not properly insulated for textile service most of the burn outs occur on Monday morning or after periods of shut down. To overcome the effects of the humidity, the windings in motors for textile service are specially insulated and treated with moisture resisting compounds, and thousands of motors so insulated have proven the adequacy of this method.

The dust proof bearings and textile insulation are features of all present-day textile motors. No special electrical characteristics are required for motors for group drive as it does not differ essentially from line shaft drive in other industries. The motors are required to start only the line shafting, and therefore require no special torque characteristics.

The group drive demonstrated the advantages of electric motor drive; the improvement in the product due to uniformity in the speed of the machines, the elimination of some line shafting, the separation and independence of departments and the ease of expansion were apparent in the motor drive, and led to steps to further take advantage of its possibilities. Consequently the so-called "four-frame drive" was developed for spinning, roving and twisting frames. These frames are placed in the mill in rows and lend to an arrangement of four machines to a group. By placing the driving pulleys of the four machines in the same alley, they come in a position to permit belting them to two double crown pulleys on one motor, mounted on the ceiling as shown in Fig. 1. The frames are provided with tight and loose pulleys and are started and stopped by shifting the belts from the loose to the tight pulley and vice versa. The motor therefore runs continually and starts without load on the loose pulleys. As the slip or speed regulation and the starting torque of an induction motor are inter-dependent, a reduction in the starting torques gives a corresponding reduction in the slip which means improved speed regulation. Every percent decrease in slip represents the same percentage increase in efficiency. The four

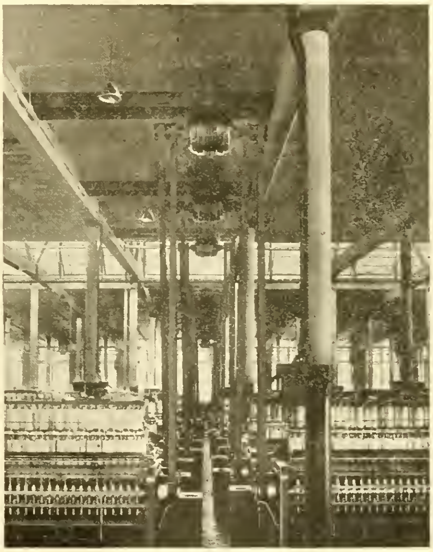

FIG. 1—INSTALLATION OF FOUR FRAME DRIVE MOTORS

frame drive motor is designed to give low starting torque with the resultant improvement in the speed regulation and the efficiency. Good speed regulation is very desirable in this type of motor on account of the fact that it must operate at ¼, ½, ¾ and full load as one, two, three or four frames are thrown on it, and a minimum variation in the driving speed with this variation in load is required. These motors range in size from 15 to 30 hp, operating at speeds of 1170 and 1760 r.p.m. and have a high power-factor. For many years motors operating at 1760 r.p.m. were used and experience shows that this high speed was responsible for much of the trouble early encountered with these motors. Any unbalancing in the pulleys at this high speed resulted in severe high frequency vibration that in time crystallized and wrecked certain parts of the motors and mountings. Small pulleys are required on the motor at the high speed, giving small area of belt contact, making it necessary to use excessive belt tension to prevent slippage; and further, the smaller the pulley the greater the jolt caused by the belt splice passing over it. Motors operating at 1170 r.p.m. are now used for four frame drive and greatly improve the operating

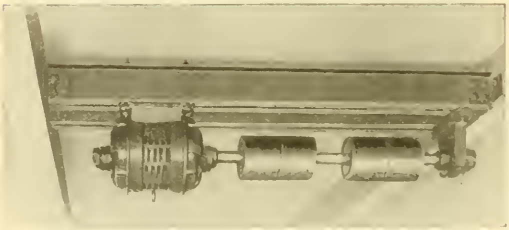

FIG. 2—UNIVERSAL-TYPE FOUR FRAME DRIVE MOTOR

condition by reducing the vibration, and increasing the size of the pulleys, resulting in lower belt tension, with increased life for the belts and bearings.

As the pulls of the four belts are at different angles no means of shifting the motors to adjust the belt tension can easily be provided. To take care of this condition and avoid frequent tightening and resplicing, the belts are cut shorter than is standard practice making them tight enough to take care of future stretching. This results in heavy belt tension that has made it necessary to use bearings 2.5 in. diam. by six in. length in the motors. This tension, together with the high speed, necessitates the use of ring oiling bearings instead of the waste packed type. The heavy belt tension also demands very rigid mountings for the motor, not only to resist the steady pull but also to reduce the vibration caused by the belt splices passing over the pulleys.

The size of these motors is such as to require that the motor design take into consideration the lint which is carried into the motor by its ventilating fans. The use of screens has been tried on four frame drive motors, but with little success, due to the inaccessibility for properly cleaning the screens and to the inadaptability for obtaining sufficient screen area to admit enough air when a thin blanket of lint collects on the screen. To take care of the lint the motors are designed without radial air ducts through the cores; and with large clearances between the windings and end brackets to allow the lint to pass through and not accummulate in sufficient quantity in a reasonable time to clog the air passage. By making the end brackets with large openings and eliminating air shields and deflectors, the interior of the motor is accessible for weekly cleaning without disturbing the motor and, in mills where compressed air is available for cleaning, only a few minutes are required to blow out the motors; or, where air is not available, the openings are large enough to admit the hand for the removal of the lint.

The four frame drive motor is built in two distinct types to take care of different aisle spacings in the mill; namely, the "double extended shaft type" and the "universal type."

Where the aisle spacing is such as to allow a motor to be placed between the two double crown pulleys without an excessive overhang of the pulleys, the double extended shaft type shown in Fig. 1 is used. Where the aisle spacing is too small to permit this, the universal type is used. Many different arrangements have been devised for this motor, but the three bearing arrangement, shown in Fig. 2, has been found best suited to the requirements. This outfit has two bearings on the motor and a third bearing at the outer end of a 46 in. shaft extension that is solid without a coupling. The middle bearing is three inches in diameter and it, together with its supporting bracket, is split to permit the replacement of the bearing without disturbing the other parts of the outfit. The outside motor bearing is smaller, as it only maintains the rotor concentric with the stator and carries very little load. With the two brackets mounted directly on each end of the motor there is no chance for the rotor to rub the stator unless the bearings wear down; a deflection in the shaft extension is not transmitted to the rotor, which is held rigidly in place by the outside bracket. The diameter of the shaft that carries the pulley is three inches and is ample to take care of the heavy belt tension encountered in this service. Two keyways, 180 degrees apart, are cut in the shaft to overcome the unbalancing caused by one keyway and key.

In order to take care of slight variations in alignment and small deflections in the shaft, the pedestal bearing at the end of the shaft extension is provided with a self-aligning type of bearing. This self-aligning feature has overcome the difficulties first encountered with the mounting and operation of the three-bearing outfit with solid bearings. The pedestal supporting this bearing is equipped with a separate steel plate under its base with the mounting bolt holes in this plate spaced the same as those in the motor feet. The pedestal is bolted to this plate with sufficient clearance

in the bolt holes to permit 1/8 in. adjustment after the plate is rigidly bolted in place, to provide a means of alignment parallel to the base; and with a clearance between the plate and the base to take shims for adjusting the alignment at right angles to the base. Once a proper alignment of the pedestal is obtained, it can be dowelled to the plate and, in case it is necessary to remove the pedestal, this can be done without removing the plate and disturbing the alignment, which will be again maintained when the pedestal is put in place and the dowel pins driven home. Many motors of this type are in service and giving very satisfactory operation.

Where the aisle spacing is so wide that the pulleys must be mounted too far from the bearings on the double extended shaft type, a modification of the universal type is used consisting in a shaft extension on the end opposite the pedestal end of the outfit. One pulley is then mounted on this extra shaft extension and the other on the shaft near the pedestal.

In some cases only two frames instead of four are driven by the one motor, giving what is known as two-frame-drive. This requires a motor of half the horse-power rating used for four frames and with single or double shaft extension of either type depending on whether the frames are placed side by side or end to end.

Each step toward the ultimate of individual motor drive was justified by the advantages obtained and demonstrated that still further advantages were possible by mounting the motors directly on each machine. Individual motor drive has now established its superiority and has been adopted for the greater percentage of the machines in up-to-date mills and is recognized by the machinery builders as the future drive for textile machinery.

To take advantage of all the possibilities of individual drive, the motor must be designed to meet the requirements of the machine to be driven exactly and this has lead to different types of motors for different kinds of machines.

As approximately 50 percent of the power required in a textile mill is used in the spinning and twisting processes, the spinning and twisting frames were among the first to receive attention in the development of the individual motor. The spinning frame motors are mostly of 5 hp, and 7.5 hp sizes, while those for twisting frames may run as high as 15 hp for large tire cord twisters. The motor speed is 1750 r.p.m. for all these frames, with the exception of the large twisters, for which 1160 r.p.m. is more suitable. The power required to drive these frames is practically all used to overcome the friction of the numerous bearings and small belts or tapes; at standstill, therefore, with the lubrication stiff and not flowing, the static friction is high, demanding heavy starting torques. The starting conditions are the heaviest after the machines have been shut down a sufficient length of time to allow the lubricant to stiffen, as is the case after the machines have stood over night. The motors must have ample starting torque to meet this condition. One of the early predicted objections to individual motor drive was the breaking of the yarn, due to too rapid acceleration of the frames in starting; this prediction was not fulfilled to any extent in practice, largely on account of the consideration given to it in designing and applying the motors. It is seen then that the starting characteristics of the motor must be just right, for too low a torque will not start the frame and too high a torque will result in broken ends. Much experience and field development has been necessary to determine the starting characteristics now used in the spinning and twisting frame motors.

To obtain this high starting torque and yet not sacrifice efficiency, the motors are carefully designed to give the best distribution of losses; and full load efficiences of 86 to 88 percent are obtained. As the

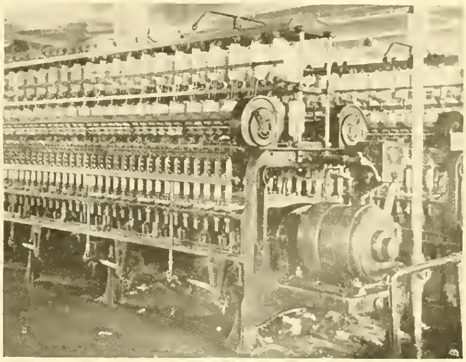

FIG. 3—INDIVIDUAL MOTOR DRIVE ON SPINNING AND TWISTING FRAMES

power-factor of an induction motor increases as the number of poles decreases, these motors which are mostly four and some six poles have a high power-factor, ranging around 90 percent at full load.

Different methods of connecting the motors to the frames are used. In some of the early drives, the motors were mounted on the floor and belted to the driving pulley on the cylinder shaft. This is not very satisfactory, as it does not eliminate the belt slippage which is one of the possible advantages of individual drive; and further the short pulley centers result in small arc of belt contact on the motor pulleys, requiring heavy belt tension to prevent slippage with resultant bearing troubles.

The speed of the driving cylinder is approximately the same as that of a six-pole, 60 cycle motor, that is, 1150 r.p.m. and lends to the direct connection of the motor to the cylinder shaft but, on account of the variation in the spindle speed required for the spinning of different yarns, the constant speed induction motor will not meet the requirement. This is an ideal form of drive and offers a field of application for the

variable speed alternating-current motor. A recent trial installation at the Mason Tire & Rubber Company, Kent, Ohio, of a variable speed induction motor of the wound-rotor type has been very successful. The motor is direct connected to the cylinder, the motor bearing replacing the outer cylinder bearing, and is operated through a controller that gives instantaneous speed variation in small steps. With this speed variation, the spinning frame can be instantaneously adjusted to meet varying atmospheric conditions in the mill and variations in the raw material. The increased cost of the motor and controller and the reduction in efficiency at reduced speeds are balanced by the elimination of the first cost and upkeep of chains and gears and the improvement in the product.

Spur gearing is used for connecting the motor to the cylinder shaft and has the advantages of a positive drive and the variation in speed by changing the gear ratios, but has the disadvantage of the lack of flexibility.

The chain is now recognized as the best means of connecting the induction motor to the cylinder shaft; it gives a positive drive with a variation in speed obtainable by changing to different sized sprockets, and possesses considerable flexibility with the elimination of much of the vibration found in the gear drive. The slight amount of slack in the chain allows the motor to rotate a small amount before encountering the load, thus improving the starting condition. The motors are furnished with tapered shafts and nuts to take the chain sprockets. Recently the machinery builders and chain and motor manufacturers have standardized the sizes of sprockets and motor and machine shaft extensions for all sizes of motors and frames. The method of mounting the motor on the spinning frame bracket and the means of alignment have also been standardized. A guide strip inserted in the motor feet and sliding in a groove in the mounting brackets maintains a definite alignment of the motor with the cylinder shaft and yet permits of adjustment by jack screws to take up the slack in the chain for different sizes of sprockets.

The size of these motors is such that the air passages are small and easily clogged, making it necessary to provide means for excluding the lint. Two effective means for the exclusion of the lint are employed on individual motors; first, totally enclosing, and second, screening the air inlets. The totally enclosed motor is the latest development in the lint proof type, but the larger the motor the more expensive this feature becomes. In the open motor, the heat produced is carried away by the air passed through it by the ventilating fans, but in the totally enclosed motor all the heat must be dissipated into the atmosphere from the external surface by natural convection. The area of the external surface of a motor does not increase nearly as rapidly as its horse-power capacity on an open basis, so that the size of a totally enclosed motor increases much more rapidly with increased horse-power than that of the open motor. Enclosed motors of 5, 7.5 and 10 hp require frame sizes suitable for 10, 15 and 25 hp, respectively, as open motors, making the enclosed type expensive. This expense is not justified by the advantages offered over other less expensive types, with the result that enclosed motors are not used to any extent for spinning and twisting frame drives.

Screens placed over the motor bracket openings through which the ventilating air enters the motors, are very effective for removing the lint from the air. The lint, however, collects in a blanket on the screen and in time this blanket becomes so heavy that the screen is completely clogged and the motor, robbed of its ventilation, overheats. But if the screens are cleaned once or twice a day, the accumulation of lint does not become heavy enough to cause trouble. The motors for individual drive are mounted near the floor and are easily accessible for the cleaning of the screens by the machine operators, and are therefore well adapted to the use of screens.

Many different kinds of screens have been used and much experimenting under service conditions has been required to determine the most effective type. Wire screens of different mesh have been tried but have not been altogether satisfactory; the fine meshes (30 to 60 per inch), in time clog up with oil and dust and cannot be wiped clean, and the coarser meshes allow the ends of the lint fibres to pass through and wind around the wires, forming a blanket that is interwoven with the screen and is very difficult to remove and in time results in a clogged screen.

A screen made of perforated sheet metal with 3/32 in. diameter perforations, seven per inch, has been found to meet the requirements best as it presents a smooth surface and is easily cleaned. The holes are small enough to prevent the lint from passing through and the width of the metal between holes is great enough to overcome the intertwining of the fibres with the screen. The screens are attached to the motors in such a manner that they can easily be removed and are made to cover the entire face of the bracket to give as large an area as possible. Screens are now standard equipment on all spinning and twisting motors, and motors equipped with the perforated metal screens show a small accumulation of lint within the motor after a years service. Screened motors should be taken apart and cleaned about once a year.

Ring oiling bearings were used in individual textile motors for many years but gave trouble, due first, to the lint gradually finding its way into the housings and either syphoning the oil from the reservoir or clogging the oil grooves; and second, to the rapid evaporation of the oil caused by the continual agitation of the oil by the oil rings. In the smaller motors, the oil reservoir is small, and for this reason a loss of oil from lint or evaporation is much more troublesome than in larger motors.

The waste packed bearing in which the oil is held in wool waste packed into the bearing housing and fed to the bearing by the wick action of the waste, is well adapted to the speeds and small torques of these motors, and has established its superiority over the ring oiling bearing for overcoming the troubles above mentioned. The waste, which is not much more than a bundle of lint, is not affected by the addition of a little more lint, and further there is no free oil in the bearing housing. In order to allow the oil soaked waste to come in contact with the shaft, the bearing has an opening in the one side extending about one half its length and one third its circumference. To avoid having the thrust of the shaft against this side of

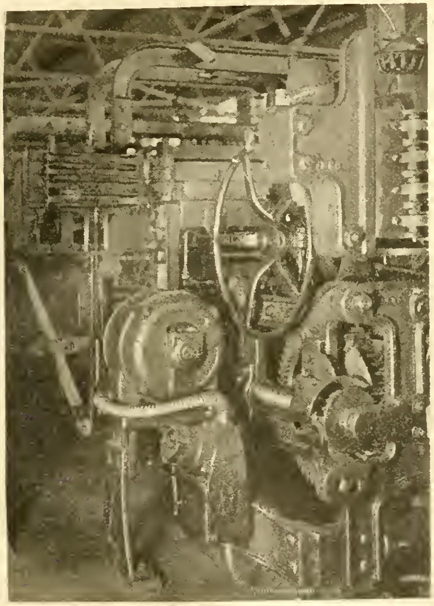

FIG. 4—INDIVIDUAL MOTOR DRIVE FOR LOOMS

the bearing (with the opening), it is necessary to assemble the bearing so that the opening is on the opposite side from the direction of the thrust.

To facilitate the assembly to take care of the different directions of the thrust the one motor bracket is assembled with the opening in the bearing on the side opposite to that of the other bracket. Then to arrange the motor for a thrust opposite from that for which it was originally assembled, it is only necessary to interchange the rear and front brackets. With this arrangement the thrust on the bearing on the end opposite from the drive end is against the opening, but this thrust is so small compared to the thrust on the drive bearing that there is sufficient bearing surface to take care of it. To make these bearing housings as tight as possible the drain and overflow plugs are omitted.

The switches for operating the motors are mounted on the ends of the spinning frames in such a manner that leads from three to five feet in length will reach from the motor to the switch, consequently the motor leads are made 5 ft. long to avoid making splices at the motor. The leads are carried in flexible conduit and the motors are provided with squeeze connectors for attaching this conduit.

From the forgoing it is seen that a motor has been developed to meet the requirements of spinning, roving and twisting frames to the last detail.

A further step in the individual drive of spinning and twisting frames is the use of a small motor on each spindle. Some experimental work has been done along this line, but has not so far resulted in a practical application. The horse-power required ranges from 1/50 on spinning frames to 1/20 on large twisters. These small motors are very inefficient and it is a question as to whether the advantages gained by the elimination of the cylinder and tapes will warrant this low efficiency. Another factor is the high spindle speed, which is much above that obtainable with a 60 cycles induction motor and means either the use of frequency changer sets or the commutator type of motor.

For driving pickers a motor identical with that for spinning is used with the exception that a straight shaft extension is provided to take a pulley; and a conduit box to permit the splicing of the long leads at the motor replaces the squeeze connector. For the double beater type of picker in many cases two motors, one on each side of the "A" frame are used, interconnected electrically to operate as one motor. In other cases a single motor of double the horse-power rating is used with a third pedestal type bearing mounted on the opposite end of the A-frame from the motor. The shaft extension on the outside end of the motor carries the pulley to drive the one beater; and the long shaft coupled to the other end of the motor is supported by the third bearing extending far enough beyond the pedestal to take the pulley to drive the second beater. This is not as satisfactory a mechanical arrangement as the two motor scheme.

The loom motor has become very popular, and is as extensively used as the spinning types, due largely to the desirable uniformity in speed obtained by the individual motor drive on the looms. The motions of a loom are reciprocating, and the torque variable over a cycle, resulting in a variable load on the motor and no small amount of vibration, demanding a motor of rugged construction. The speed of the loom is low, and as the motor is geared to the main driving gear, a small pinion is necessary on the motor shaft to give the reduction from motor speeds of 1160 and 1750 r.p.m. This gear drive requires a tapered shaft extension on the motor, and relatively large substantial bearings to withstand the pounding from the gears and the variation in load. To meet this requirement bronze bearings of the waste packed type are used. The bearings with their supporting brackets are so arranged that

they can be turned through 360 degrees in steps of 90 degrees for floor, wall or ceiling mounting, with the opening in the proper position for the thrust from the pinion.

Two methods of connecting motors to the looms are employed; in one case the motor and gear are rigidly connected to the driving shaft, while in the other a friction clutch is inserted between the large gear and the driving shaft. In the first case the motor starts and stops with the loom, and must have a large starting torque to overcome the bearing friction and inertia of the moving parts; the high torque loom motor is designed to give this torque with as high performance as possible. In the second case the motor starts light and runs continually; the starting and stopping of the loom is preformed by the clutch. The starting torque of the motor can be reduced to a minimum, as has been done in the low torque type of loom motor, which therefore has slightly better performance than the high torque type.

FIG. 5—VERTICAL MOTOR FOR DRIVING SILK SPINNERS

Looms require motors ranging in size from one-third hp on the smallest cotton looms to three hp on large carpet looms. Following inversely the same line of reasoning previously given for enclosed spinning motors, it is seen that the smaller loom motors have relatively large external surfaces and are adapted to totally enclosing without increasing the frame to such a size that its cost is offset by the advantages obtained. Almost all loom motors are totally enclosed and are lint proof in the full sense of the word. They are provided with squeeze connectors to take flexible conduit for the leads and have windings treated to withstand the humidity, even though they are enclosed.

There are no installations of individually driven cards at the present time, the group drive being used entirely. A recent trial drive has demonstrated that there is nothing impossible nor very special in the design of a motor for this drive, and that the card will soon fall in line with the other machines for individual drive.

All that has been previously mentioned has applied more directly to the cotton and woolen industries, but the silk industry has also received its share of consideration in the development of individual drive motors. Many of the special features required for the cotton and woolen mills apply also to the silk mill, with the exception of those for taking care of the lint. The silk worm is a very expert spinner and produces a thread that does not throw off its fibres when being worked through the different processes, so that there is no lint to fly in the air in the silk mill to bother the motors.

The silk spinning and twisting frames differ from those for cotton or wool in that the driving shaft is in a vertical instead of horizontal position, and the vertical motor is, therefore, more suitable for direct connection to the vertical shaft. Horizontal motors have been connected through bevel gears to the frames; but the loss in efficiency and vibration in the gears has been a serious objection.

The special vertical motor shown in Fig. 5 has been developed to mount in the end frame and couple directly to the driving shaft of the type *B* and type *C* Atwood silk spinners. This type of motor is built in two and five hp sizes at 870 r.p.m. and is so designed that the end frame of a spinner of either a new or existing installation can be set onto the special base of the motor, and the motor coupled to the drive shaft, with very slight modification in the end frame. The height of the motor has been reduced to a minimum. For driving other types of spinners that are not adapted to the above motors, a vertical motor with a pulley mounted directly on a shaft extension on top of the motor can be belted to the vertical drive shaft.

There are other machines in the textile mills that are individually driven by motors and not been mentioned here, but the special features of the motors do not differ from those already covered. There is no reason why every machine in a textile mill cannot be driven successfully and better than before, by a direct-connected electric motor.

Individual Motor Drive for Spinning and Twister Frames

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SPINNING frames are machines used in textile mills for reducing the prepared raw material in the form of a soft cord, called roving, to a firm fine thread called yarn. They perform the processes of attenuation and spinning. Practically all American yarns are spun on ring frames. In these frames the bobbins of roving are placed in a creel, the ends carried through rollers running at successively higher speeds, through proper guides and thence through a traveler to the spindle bobbin. The traveler is a small metal loop running on a highly polished circular track called a ring. All the rings of a frame are raised and lowered together by the traverse mechanism, so as to wind the yarn on the bobbins. Generally speaking, spinning frames carry from 204 to 272 spindles.

Twister frames are very much like spinning frames, except that spools of yarn instead of roving are placed in the creel and the function of the frame is to twist two or more of these yarns together so as to form a larger and stronger yarn. In wet twisters the yarn passes through a water bath before being twisted.

Spinning and twister frames are interesting in that they embody the use of highly perfected, accurately balanced spindles running at speeds of approximating 10 000 r.p.m.

In the older frames the spindles are driven from a tin cylinder, by means of a round band. In the new frames the spindles are driven from a similar cylinder by a flat woven tape, using one tape for four spindles. Uniform tension is maintained on this tape by means of a weighted idler.

In earlier installations the frames were driven from water wheels or engines by pulleys and belts. Large group electric motors were next used, the only material gain being the elimination of the heavy head shafting. This gain was, of course, offset by the motor losses. The next system was to use one motor with shaft extension and four pulleys to drive four frames. All of these drives while reasonably satisfactory embodied the use of at least one belt. Countershafting belts show a slight amount of slip but the real offender is the final belt from the shafting or four frame motor to the frame pulley. This is an almost vertical belt exposed to oil and lint and in spite of daily cleaning will show an appreciable amount of slip. Each decrement of speed represents at least a corresponding decrement of production. The output of a frame is a maximum when it is adjusted and equipped for a certain proper speed. Any decrease in speed will cause a somewhat greater percentage loss of production than the percentage speed change.

Individual motors are applied to spinning and twister frames with the object of eliminating belt slip and thereby increasing production. The general acceptance of this drive was delayed due to the lack of a satisfactory connecting transmission between the motor and the driven machine. The earlier drives used direct connection through couplings. In some cases rigid couplings, and in others friction clutches were used. These drives did not allow of any speed adjustment, and were unsatisfactory, principally from this standpoint. For direct connection it is generally necessary to use 1150 r.p.m. motors which are, of course, more expensive, less efficient and bulkier than the 1750 r.p.m. motors.

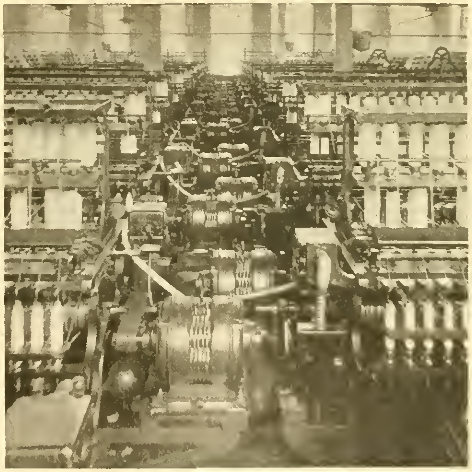

FIG. 1—SPINNING FRAMES FORMERLY DRIVEN BY BELTS FROM OVERHEAD SHAFTING

Individual motors with silent chain drive were installed without moving the frames.

Following the direct-connected drives, spur gearing was tried, and such materials as fibre, raw hide and fabroid were used. These gears proved only partially satisfactory, and generally vibrated badly, with resulting noise and rapid wear.

The next and most important step in this transmission was the use of the so-called silent chains on short centers. This combination, when used with

rigid cast-iron supports, has proved very satisfactory.

The standard chain drive equipments for 5 and 7.5 hp drives are 2.5 to 3 in. wide, using ½ in. pitch, 9.5 or 10.5 in. centers, and chain speeds approximating 1500 ft. a minute. Driving sprockets usually carry 21 teeth, and the number of teeth in the driven sprockets is varied to give the required speed. One manufacturer recommends the weekly use of grease for the lubrication of his drives, and another recommends the use of an oil bath. In the latter case a disc on the driven sprocket dips into the oil and throws it to the top of the casing, from which it drips on to the chain, providing continuous lubrication.

The requirements of practically all spinning frames today are met by the application of 5 or 7.5 hp, 1750 r.p.m. induction motors. Twister frames, depending on the size of the frame and material handled, require from 5 to 20 hp motors. Ninety per cent of all the motors installed would be either five or 7.5 hp. These motors differ only slightly from standard induction motors, but have the following special features:--The shafts are tapered and provided with nuts and lock washers for the proper holding and easy removal of the chain sprocket. Bearings are of the waste packed type, providing a sturdy, easily maintained bearing and eliminating the possibility of trouble from the hanging up of oil rings. Terminal fittings and extended leads are provided to obviate the use of joints at the motor terminals, these leads being long enough to reach from the motor to the controlling switch. Screens are generally provided over the motor heads to prevent the entrance of bulky masses of lint or other foreign matter.

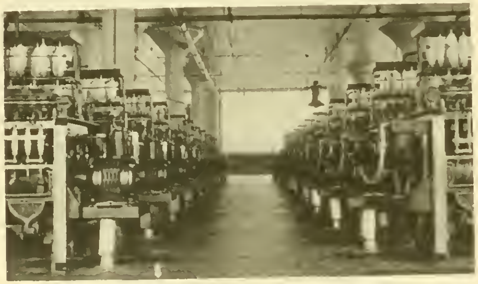

FIG. 2—INDIVIDUAL MOTOR DRIVE OF NEW SPINNING FRAMES

Standard characteristics for these individual motors are 3 phase, 60 cycle, 550 volts, with occasional installations of 220 volts and special installations of 25 and 40 cycles or 2 phase .

In nearly all cases starting conditions are normal, approximating constant torque from rest to full speed. Simple non-automatic switches are generally used, and the motors are connected directly to the line in starting. For heavy twister frames special precautions, such as starting compensators, should be provided to prevent excessive starting torque and consequent breakage of the driven machine parts.

The oil switches are sometimes operated by shipper rods and sometimes by hand. The latter method seems to be increasing in favor. Another development is the use of a magnetic switch controlled from push button stations. While slightly more expensive, this forms a very convenient and flexible method of control.

Automatic oil circuit breakers are hardly justified for the protection of these motors, and non-automatic switches are generally used in connection with fuses. Obviously these fuses, in order to carry the starting current, must be too large to protect the motor against overload. As a matter of fact, an overload developing in the machine is a very unusual thing, and the greatest cause of motor burn-outs is single-phasing. It is, therefore, desirable to make these protective fuses just as large as possible, in order to prevent single-phasing. Recently the insurance companies have approved the use of time limit fuses which will carry heavy instantaneous starting currents, but will safely blow after small, continuously applied overloads, and these devices will probably prove to be the best protection available. It is, of course, essential that the frames and motors be properly grounded in order to avoid accidents.

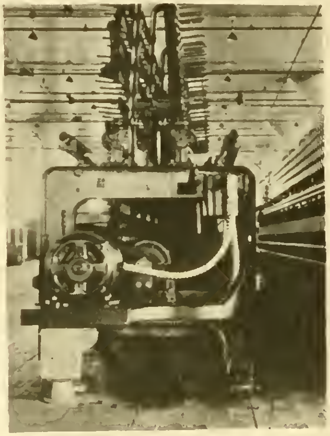

FIG. 3—INDIVIDUAL MOTOR DRIVE FOR TWISTER FRAMES

So far, the variable speed motor has not been generally accepted. Its cost is high and its speed changes with varying voltage. Especially with purchased power, this condition will have to be met by the installation of automatic feeder regulators, which will in turn add to the first cost of installation.

The bogey of high room temperatures is, of course, a fallacy. These motors are just as efficient as any combinations of mechanical or group motor drive. Therefore, the total number of heat units liberated in a given room will be approximately the same. Of course, the individual motors feel warm, as their energy losses emanate from a small surface and within

reach. On the other hand, all this heat rises to the ceiling and a great part of it there passes out of the top of the room, whereas, with belt drive from above, the heat is fanned down to the lower levels of the room. The efficiency and power-factor guarantees on 5 and 7.5 hp motors made by one manufacturer are given in Table I. In addition to the main advantage of increased production are the advantages of greater cleanliness and far better lighting of the room.

Recently steps have been taken by the several manufacturers to standardize such details as the dimensions of motor shafts, feet alignment spline and driven shaft. This, it is hoped, will lead to considerable economy and, possibly, to the interchangeability of parts.

It might be feared that installations of individual motor drives would necessarily operate at abnormally low power-factors. From practical experience and as

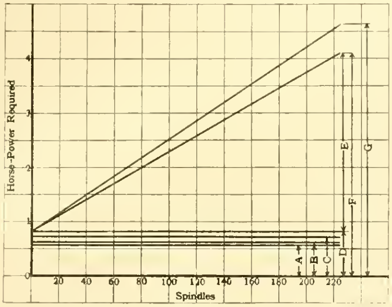

FIG. 4—POWER REQUIRED FOR DIFFERENT PARTS OF SPINNING FRAME

The results are averages of several tests made on a Saco-Lowell spinning frame having 224 tape driven spindles with 30's yarn warp and driven by a 7.5 hp, 1800 r. p. m. motor.

A—Cylinder only, 0.569 hp or 12.2 percent. *B*—Cylinder and traverse, 0.608 hp or 13.1 percent. *C*—Cylinder, traverse and one front roll, 0.731 hp or 15.75 percent. *D*—Cylinder, traverse and two front rolls, 0.807 hp or 17.4 percent. *E*—224 spindles only, 3.343 hp or 72.2 percent. F—Complete frame less yarn, 4.15 or 89.6 percent. *G*—Complete frame, 4.64 hp or 100 percent. Travelers and creel only, 0.49 hp or 10.4 percent.

a result of a number of tests it is gratifying to say that the power-factors of these installations are reasonably good, averaging between 79 and 85 percent, depending on conditions. This is especially interesting in view of the fact that frequently 7.5 hp motors are provided on spinning frames requiring only 5 hp at the time of installation. The extra motor capacity is provided to take care of any probable change in the requirements of the frame, such as higher speeds or heavier yarns.

Records of motor burnouts show low costs from this source. Generally speaking, a mill with a large installation, say of 200 spinning frame motors, will burn out probably two to six motors in a year. Ordinarily one or two motors are carried as spares and a substitution can be made with little loss of time.

Very little information is available on the life of individual motors in this service. One of the oldest

TABLE I—MOTOR CHARACTERISTICS

H. P. Rating	Efficiency			Power-Factor		
	½ Load	¾ Load	Full Load	½ Load	¾ Load	Full Load
5	84	86	86	73	83	87
7.5	83	86.5	87.5	72	82	87.5

installations in the territory, that at the Anderson Cotton Mills, is still in operation and the motors are apparently good for years to come. They are now about twenty-five years old. Installations of five to ten years age show very little depreciation.

A curve made from actual tests is shown in Fig. 4 to illustrate the power taken by the several elements of the spinning frame and the frame when operating complete. The results of a large number of tests show that the power of spinning and twister frames varies with the spindle speed, the yarn number, traveler weight and various other factors. Also with such variables as band tension, viscosity of lubricant, etc.

The growth of individual motor drive in the southeastern territory in Fig. 5 is probably representative of the total growth in this country. About 13 percent of the spindles are individual motor driven, leaving a considerable field for these applications.

It is difficult to make any definite statement as to what increased production can be had by motor drive over belt drive. This increase would depend, not on the individual motor drive, but on the condition of the belt drive with which it is compared. If the belts have

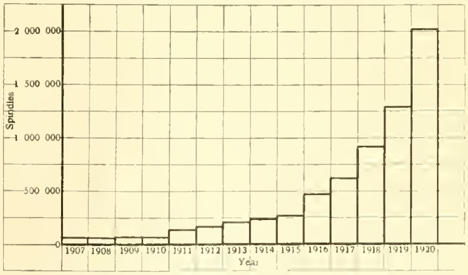

FIG. 5—INCREASE IN INDIVIDUAL MOTOR-DRIVEN SPINNING AND TWISTER SPINDLES SINCE 1907, IN SOUTHERN MILLS ONLY

been exceedingly well maintained, a small increase only might be expected. Increases as high as ten percent have been reported, but conservatively speaking, an average of five percent would probably be fair.

Motors for Textile Finishing Plants

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THE adaptation of the electric motor to machines for finishing cotton, and cotton and silk piece goods presents to the engineer many problems quite apart from those in the field of electrical engineering. The convincing arguments set forth for the use of the electric motor in the broad field of manufacturing apply to cotton cloth finishing plants; but they are not the strongest arguments which may be used.

The electric motor is applied to industrial machines for one or both of two reasons. It must have been proven to be a more efficient method of transmitting power from the shaft of the prime mover to the shaft of a machine, or its advantages as to speed regulation and control must bring about an increased production in the machine to which it is attached, directly or indirectly.

To state the advantages of the electric motor in the finishing industry as a transmitting device would be but to repeat what has been written on the subject during the last ten years; but its qualifications as a money-making device in that industry are not so familiar to designers and manufacturers of motors as they are to the engineer who has had occasion to study in detail its actual effect upon the production and economical operation of certain classes of finishing machinery.

In cotton cloth finishing, power is divided into mechanical power for driving machines, power for pumping vast quantities of water, light, heat for warming buildings, and heat in the form of high and low-pressure steam used for boiling and drying operations.

Roughly speaking, 40 percent of the steam leaving the boilers will be used in the form of high-pressure live steam and 60 percent will be delivered to prime movers. Of this 60 percent, one-half will ultimately drive constant-speed machines and one-half variable-speed machines.

In a well-designed plant, all of the heat used in producing mechanical power, with the exception of that lost by radiation and through condensation in prime movers, can be recovered and used in the processes, resulting in a reduction of the amount of live steam taken directly from the boilers for process purposes. The average finishing plant does not run in any such ideal way; but wastes a large amount of heat incident to producing power, and generates more heat for process purposes. It has, however, been proven that there need be no waste of heat in a finishing plant, other than the unavoidable losses in transmission; and the electric motor has been responsible for this improvement. It is worth while to reduce a fuel bill of $50 000 to $25 000 through an ultimate expenditure of perhaps $75 000; and that this is possible is due in a large measure to the almost ideal characteristics of the adjustable-speed motor as adapted to finishing machines which must be driven over a considerable range of speed.

As stated before, a considerable part of the machinery in a finishing plant must be driven at varying speeds. Expressed in actual horse-power, this may be from one-third to one-half of the total, depending upon the kind of finishing that is done. Until the advent of the adjustable-speed motor, these varying-speed machines were almost universally driven by small engines, most of them being two-cylinder inclined engines with cranks set 90 degrees apart, cylinders unjacketed, cutoff fixed at about one-half stroke and rating from 5 to 30 horse-power, according to the machines to which they were attached. If these engines were in good condition they would develop a horse-power with from 60 to 65 pounds of steam. As actually operated, they took from 80 to 100 pounds of steam per brake horse-power.

Fifteen or twenty of these engines, located around the plant and developing one-half or less of the actual horse-power required, would take more steam than the main prime mover which drove the constant-speed machines through the usual line shaft and belts, or even through electric-motor drive applied to constant-speed machines only.

There are three types of these engine-driven varying-speed machines, viz.:—drying cans (using a comparatively small amount of power but a large amount of low-pressure steam for drying purposes), printing machines (using a considerable amount of power and a small amount of low-pressure steam for drying purposes), and tentering machines (using a moderate amount of power but no steam at low pressure as usually set up).

In the first case, the exhaust steam from the engine is used in the drying cans, but at least an equivalent amount must be taken from the live steam mains, reduced in pressure and introduced into the cans to provide the heat required. In the second case, the amount of steam exhausted from the engines is greatly in excess of that which can be used in the machines. In the third case, all of the exhaust steam must either be thrown away, or diverted to machines which can use it.

The solution of this problem might appear to be to run a low-pressure main around the plant, exhausting all engines into it, and taking all low-pressure steam from it. This is the method ordinarily used to

conserve heat, but the final result is that the balance between departments is such that it is practically impossible to make the supply and demand equal. In almost every instance the amount of exhaust available from the many small engines was more than sufficient to supply all of the heat, with the result that the heat exhausted from the main unit driving constant-speed machines was entirely wasted, sometimes to a condenser and sometimes to the atmosphere.

While the small engine might appear to be wasteful of heat, it would ordinarily be given credit as being a very flexible and easily controlled variable-speed device with an infinite number of speed changes between maximum and minimum. As a matter of fact its speed control is very poor; and it is almost impossible to get fine graduations of speed with an ordinary throttle valve operated by the machine tender. The effect is somewhat similar to that of an electric motor having four or five points of speed control. Furthermore, if an engine is slowed down temporarily and an attempt is then made to bring it back to its previous speed, there is little assurance that the speed will be the same; and, in those machines in which the speed should be limited only by the capacity for drying, it is seldom that the highest possible rate of production is obtained with the engine drive.

Consider now, the first case mentioned, that of the set of drying cans, which will take eight horse-power to drive and 2000 pounds of steam at two or three pounds pressure. The engine will exhaust, say, 700 pounds of steam per hour, leaving 1300 pounds to be made up from some other source. If this 1300 pounds of steam is taken from the live steam main and reduced to two or three pounds pressure, no mechanical work has been obtained from it, although it might be made to produce 30 kilowatts per hour of energy and still deliver 90 percent of its heat to the drying cans. This 30 kilowatts of energy, however, is probably being turned out in a main unit utilizing less than five percent of the heat delivered to it. Take the engine from these cans and attach an eight hp adjustable-speed motor. This motor will derive its power from a main prime mover running non-condensing and exhausting into a low-pressure main from which all low-pressure devices can take their steam. To drive this eight hp motor the prime mover will take 350 pounds of steam per hour as against 700 for the small engine. The drying cans will take 2000 pounds of steam per hour which will be exhaust steam from the main prime mover; and in the process of producing that low-pressure steam the prime mover will deliver to the line 45 kilowatts of energy, the heat in one-quarter of which has been used to drive the drying cans. The 37 kilowatts of energy produced in the operation of supplying low-pressure steam to the drying cans becomes available for the constant-speed machinery, and has been produced at practically no cost other than the fixed charges upon the equipment.

In the second case, that of the printing machines, the maximum power required will be 30 hp, but the average over any considerable period of time will probably not be more than half of that, or say 15 hp. These engines will have large cylinders in order to provide the excessive starting torque which is required, with the result that the water rate will be worse than even in the case of the power engine. We may take, however, as an average, 1200 pounds of steam per hour; but only half of this will be required in the operation of the printing equipment, leaving 600 pounds to be delivered elsewhere. It is by no means certain, however, that this additional steam can be used at just the time that it becomes available. Furthermore, we have only been able to get 15 hp out of the 1200 pounds of steam delivered to the engine, whereas we might have obtained 27 to 28 kilowatts from the same amount of steam if delivered to the right kind of a prime mover, or sufficient energy to drive two printing machines.

In the third case the condition is simply aggravated still further, inasmuch as the engine will be called upon to deliver about ten horse-power, and will take 800 or 900 pounds of steam per hour (which may or may not be used by other machines according to whether it is needed). The real trouble is, however, that so little power has been produced in the operation of reducing the steam from boiler pressure to low pressure, making it necessary to generate more power in a large unit.

The heat balance in a finishing plant is such that the entire mechanical power needed can be produced in the process of reducing steam to low pressure, through the use of a single generating unit exhausting at, say five pounds gauge pressure or less.

It is apparent from the foregoing, that the adjustable-speed motor has made possible two great improvements in the finishing industry:—First, the substitution of one main generating unit providing all of the power required for the entire plant, all of the exhaust steam from this unit being used in the processes, and a net fuel use of less than one-half of a pound of coal per kilowatt-hour; and, second, any range of speed that may be required, with a delicacy and sureness of control that cannot possibly be obtained with steam engines.

As to the power characteristics of the varying-speed machines, there is much that may yet be done in the way of careful study that may make possible the use of motors especially adapted to this work. Up to the present time, standard adjustable-speed motors have been used, seldom with a speed range of more than four to one, often with a speed range of two to one; but perhaps most generally with a three-to-one range. Adjustable-speed motors are usually rated on a constant horse-power basis, whereas most of the varying-speed finishing machines more nearly approach the constant torque basis. A standard 10 horse-power,

adjustable-speed motor having a speed range of from 500 to 1500 r.p.m., will usually develop 10 horse-power at any speed within those limits. As applied to a set of drying cans it will be called upon to deliver 10 horse-power at 1500 r.p.m. and the horse-power will decrease with the speed, not exactly in proportion but nearly so. At 500 revolutions-per-minute, it may be called upon to deliver 4 or 4.5 horse-power.

At the higher speed, the heating of the field is a minimum, and the cooling effect through windage a maximum. On the other hand, the armature current is the maximum at the highest speed. At the lowest speed the heating of the field is a maximum, the cooling effect is the minimum, but the armature current is also at a minimum. It is a fact that in most cases the standard adjustable-speed motor will run hottest at the lowest speed, notwithstanding the comparatively low horse-power.

The motor may be called upon to run continuously at the highest speed for perhaps the entire day, and it should have a continuous rather than an intermittent rating. The average speed over a considerable period of time will be from one-half to two-thirds of the maximum; and in many cases the maximum will only be used for special goods and for a brief period of time. The motor, however, must be capable of running satisfactorily, and develop the maximum horse-power at maximum speed, if for only one day in the year.

For printing machines, the characteristics are somewhat different. The load is constant torque for any given work, i.e. with certain patterns in the printing machines the load will vary nearly with the speed; but if the pattern is changed, the torque for any given speed may be very much more or less. About 30 horse-power maximum is required by a printing machine. For patterns which involve heavy torque the speed may be high for many hours, requiring the motor to develop its full rated load at maximum speed.

The starting torque of these machines is also high, and may require 150 percent of the maximum running current for the initial start. This, however, is for but a few seconds. There are a great many classes of work, however, in which the maximum speed will not require over 12 to 15 horse-power, and in which the starting torque is not excessively heavy. It is probable that a printing machine motor, averaged over an entire year, would not develop 15 horse-power; but there are periods of time when it will run for many hours at its maximum rating.

Motors on tentering machines have very nearly constant-torque characterisitcs for about all classes of work, and seldom run at the maximum speed, but must do so when required.

Adjustable-speed motors lend themselves to driving ranges of machines where there are two, three or four units which must run in synchronism or practically so, but controlled as one unit. The writer believes that he made the first installation of this character in a finishing plant some twelve years ago, in which two units were previously coupled mechanically through long shafts, bevel gears, friction cones, etc., and driven by one variable-speed motor of the multiple-voltage type. The shaft, gears and cones were dismantled and two motors used on one controller, with auxiliary field control for one of the motors to take up the slack between the two units of the range. This worked so well that an addition was made in the form of a device in which the slack between the two units would automatically bring about a slight change of speed in one of the motors, so that no manual labor was required to maintain the exact speed between the two units of the range. This has now become almost standard practice in finishing plants for dye ranges, tenter frames and similar machines.

One of the most difficult problems to solve satisfactorily is the transmission of the power from the motor shaft to the machine shaft. In many finishing machines the main driving shaft runs at slow speed, in some cases as low as 60 r.p.m. In some cases, the machines to be driven are hot and it is undesirable to locate the motor close to them, even if the speed characteristics permit. Where temperature conditions are favorable, the silent chain drive is satisfactory, as large speed ratios can be obtained without complication. In a few cases worm-gear drives have proven satisfactory; but in the main these are inefficient. Back-geared motors have been used, but these are again more or less special.

Motors in a finishing plant are subject to high temperature and an excessive amount of moisture. It is, therefore, wise to standardize, in so far as is possible, both as regards horse-power ratings, speed ratings and character of control, and be able to replace motors quickly with spare motors on hand. This does not mean a burdensome amount of spare equipment, but one, two or three spare motors may save a great deal of lost time. It is not necessary that all of the sizes be carried on hand, as a large motor can be temporarily adapted to a low horse-power machine, if the speed is right.

As to control, up to within three or four years, the simple, non-reversing, machine-tool type of drum controller was acceptable. There were three or four points of armature resistance which were useful in starting machines up and running them very slowly for cleaning or for special adjustment. There were then from fifteen to twenty field contacts to give the actual variation in speed throughout the normal range of the motor. This type of controller must still be considered as having many desirable characteristics. It is simple and requires little attention to insure continuous functioning. Used in connection with an under-voltage and over-load relay, the motor is amply protected.

The push-button, predetermined speed type con-

troller has gained in popularity, due largely to the fact that it is more "fool proof." Controllers in a finishing plant are subject to much abuse, and if the operator can be confined to manipulating a rugged push-button, the repairs and lost time are reduced. The push-button predetermined speed type controller consists of a frame with slate front carrying main line contactor, relays, under-voltage and no-voltage release, armature resistance with contactor, etc. The auxiliary equipment consists of a push-button device which will give a start, stop, slow speed, fast speed, and an inching. The *Slow* speed is used for making the adjustment after the machine is started and is obtained through the use of an armature resistance which is cut out of circuit when the *Fast* button is pushed. The *Fast* button gives a speed dependent upon the setting of the field rheostat which is mounted nearby and within easy reach of the operator. If the *Stop* button is pushed, the machine will stop promptly through the dynamic breaking action of the motor; and if the *Fast* button is then again pushed, the machine will be brought up to the same speed at which it was running before it was stopped, without further manipulation on the part of the operator. This type of controller has materially reduced the number of fuses required, as both the starting and the stopping current are held within a definite range through the action of the controller itself.

Where there are two or more units in a range, each unit driven by its individual motor and all of the motors operated from one controller, the field rheostat may have capacity for all of the motors; but in many of these ranges it is desirable to operate one of the units without the other, and in such cases it is a better arrangement to have individual field rheostats for each motor, but coupled on one operating shaft. It is then possible to operate any individual unit by simply disconnecting the other from the line.

Up to the present time there is no satisfactory substitute for the direct-current, adjustable-speed motor for this class of work. Plant owners and engineers would certainly welcome an adjustable-speed motor that would operate on an alternating-current circuit, and would have shunt motor characteristics. The slip-ring type of motor does not have enough variation in torque characteristics to give good speed regulation. Furthermore, the efficiency and power-factor are not satisfactory. It is for this reason that many finishing plants have adopted the direct-current motor for the entire equipment, whereas the alternating-current motor possesses the usual desirable characteristics for the constant-speed machines.

A number of plants are using alternating-current generating equipment and alternating-current motors for constant-speed drives, operating a motor-generator set to provide direct current for the varying-speed machines. This is a very desirable arrangement and, by properly proportioning the motor-generator set, considerable power-factor correction can be obtained.

Plants have been built with an alternating-current generating unit and a direct-current generating unit, with the two tied together electrically through a motor-generator set. In case it was necessary to operate overtime, either unit could be run according to the preponderance of current of one kind or another, and the motor-generator set used to deliver either alternating or direct current as required. This arrangement possesses no great advantage over the single-unit plant.

Central Station Power for Textile Mills

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TEXTILE manufacturers have had to go through a process of education before they could be brought to see the necessity of making investments in electric drive. Their mechanical drives were the development of many decades, their advantages and disadvantages were known by experience.

The first objection they raised was that the power source was placed in the hands of others. Considerable argument was required to convince operators that the central stations had to deliver as good or a better service, if it was to continue its existence; and that the central stations had made tremendous investments to give reliable service.

Then again electric motors were unknown factors, and some of the first installations of electric drive were not as efficient as they are at this date. The feasibility of the claims of increased production, offered by the central station, were doubted. Such figures and statements as were given were looked upon with distrust, as being biased. "Doubting Thomas" had nothing on the mill man who had used mechanical power for 20 years or less.

Cost of operation was a battle fought many times, cost per horse-power instead of cost per pound of products was the banner that men fought under, and pounds per spindle product was only discussed in the absence of the practical superintendent. However, today the manufacturer who has once used electric power from a central station never goes back to the mechanical drive.

The present status of the electric textile drive shows that there are today approximately 12 000 000 spindles, in the United States, driven by the power supplied over the transmission lines of the central sta-

tions. Practically 29 percent of the spindles in the United States depend on a source of power controlled by companies outside of the mill itself. As to the dependability of service rendered, the record of one company driving four and three quarter (4¾) million spindles, shows an average of operating time on its entire system of 100 percent delivery of time, less 0.1683 of one percent for 24 hour service throughout the entire year.

When the textile manufacturer realizes that the central station investment is one of large magnitude, and the earning capacity of which varies in the direct ratio of the efficiency of its service, then he will have no lingering doubts on the question of dependability of the central station service, and will follow the experience of some of the largest textile plants in the United States.

The application of the proper type of electric drive has had the intensive study of the best electrical, mechanical and textile engineers of the country, some misapplications have been made during the past due to the lack of textile knowledge by the electrical engineers, or the lack of electrical knowledge by the textile engineers. However, the close co-ordination existing between these engineers today has made the highly efficient and practical adaptation of the electrical and mechanical knowledge to textiles possible, resulting in greater production per spindle and flexibility of operation, than was possible with the mechanical drive. Power cost per pound is now known, not only in the textile plant as a unit, but, in each department, carding, spinning or weaving is calculated or measured to an accuracy that is not possible with mechanical drive.

There is no more economic reason why the textile plant should make its own power, than that it should make its own bobbins or shuttles. The primary business of a textile plant is manufacturing cotton goods. Incidentally, it is a manufacturer of as many other products as it may see fit. Some plants have gone so far as to make their own sizing compounds, but few manufacturers would endorse that plan. The manufacture of power by textile plants has been conducted by them because the delivery of power by central stations is a comparatively recent development compared with the textile business, and had not reached its present stage of perfection coincident with the cotton mill.

The writer knows only too well the many fallacies of deductional reasoning from figures, but curves of past experiences would indicate that the most conservative estimate of the future textile growth should be placed at 500 000 spindles yearly for the next five years. Assuming 30 spindles per kw, then the yearly increase in power demand would be 16 600 kw or 50 000 000 kw-hrs. There is a great probability that two-thirds of this power will be required by the states south of the Mason and Dixon line; fortunately these states have a larger share of hydroelectric possibilities than the northern states. While in the past the Atlantic seaboard has had more of this class of industry, the present indications are that there is a strong tendency to locate plants near the cotton fields and the less expensive hydroelectric power. At present, the writer has applications from textile plants for over 15 000 kw that are unfilled, and unless new hydroelectric plants are developed, those plants will have to generate their own power (either mechanical or electric) with a further increase of coal movements added to an already congested traffic.

Any State having water running to waste in its undeveloped rivers is guilty of an economic crime, it is wasting the "white coal" and burning "black coal". "Selling its birthright for a mess of pottage" is a weak simile compared to the State which does not cash in on its possible hydroelectric power. It does not "shop at home", it is enriching another State with a purchase, hinders the development of its own possibilities and aids in depleting the country's coal resources.

Experience shows that (with a few exceptions) the textile plant built near the site of a small water power has more disadvantages than those located near a town or a city. The better class of labor has objections to living where it can not get the "benefits" of city life. Usually the class of labor content to live "in the sticks" are less efficient, than those enjoying the pleasures and educational advantages secured by close proximity to cities. Mills built at or near comparatively large centers of population manufacture their own, or purchase, power without any seeming handicap from the "free power site" mill. Power is only about five percent of the manufacturing cost, and many mill men have declared that they would not accept such a power site if it was conditioned on building a plant thereon.

As between purchased power or manufactured power, the former, if generated by steam plants, has many of the disadvantages of privately manufactured power during coal strikes, railroad congestion, and fluctuating prices; while the hydroelectric purchased power, being more stabilized as to price and quality, is without question the more logical answer of the power problem. Experience shows that in speed regulation and continuity of service it is the equal of the large privately owned plant, and superior to the privately owned medium or small plant. The same is also true regarding flexibility of operation and operating cost.

Each State should encourage the formation of companies to develop its natural water power resources, and also see that its laws treat such companies in such a manner that investments are secure and give a proper return. Due to the greater risks in hydroelectric developments than in other lines of business the returns should be greater so as to create an inducement to increase the public wealth by the development of the natural water power resources of the State. There are something like 50 000 000 undeveloped horse-power in the rivers of the United States. For years this enormous supply of power has been running to waste, and will continue to run to waste unless the

public policy is changed toward the corporations and the investors who have heretofore taken the risk of building hydroelectric properties.

Public Service Commissions, by virtue of the powers conveyed to them by legislatures, have taken away the right of barter from power companies and central stations. In return the obligation is imposed on them to see that the utility is assured a fair return for its investments. Too often commissions fix rates that will not allow a repeating investment. They do not allow a return that will induce capital to duplicate their investments. Certainly such a return should be given as would enable water power bonds to compete with State and municipal bonds that do not have the hazards of water power developments. If the Railroad Commmissions or Public Service Commissions were also charged with the obligation of securing the capital and men necessary to develop the state hydroelectric possibilities, their ideas of just and reasonable return would undergo a change. The problem of power supply is, and should be, of intense interest to the textile manufacturer. By eliminating an investment in a power plant, he can, at the same cost, increase the number of producing spindles by at least 15 percent, and dividends are made on his spindles and not his power plant.

Adjustable Speed Motors and Control in Finishing Plants

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FROM the viewpoint of the plant engineer or master mechanic it is unfortunate that certain machines in almost every factory require adjustable-speed operation to produce the work expected from them. Textile mills and, in particular, textile finishing plants are no exception to the rule, and adjustable-speed drive must be supplied for various machines—the most important being tenters, starch mangles, calenders, dry cans and printing machines. The best possible speed control should be used, especially on print machines, for the quality of printed cloth depends largely on being able to adjust the speed easily to the pattern being printed.

Both alternating and direct-current motors have been used for adjustable-speed service in finishing plants and the former have met with varying degrees of success. However, to achieve the best results, from both the operating and the production point of view, direct-current motors and automatic control are essential. This applies to printing machines in particular. Though textile machines in general requiring variable speed, are of the constant-torque type, so many elements enter into the driving of printing machines that they can be met to best advantage only by a commutating-pole, adjustable-speed, direct-current motor with push-button, automatic control. Some day, an alternating-current motor may be produced with speed-torque characteristics comparable to those of a shunt motor, but it is not now available. On the other hand tenters, mangles and calenders can be acceptably driven by slip-ring, or wound-rotor motors, for in these cases close adjustment of speed is not needed.

Another consideration enters into this problem:—the quality of product handled by the mill. Naturally, a mill finishing the cheaper grades of cloth or printing only in few colors, does not require the same degree of refinement in driving apparatus as mills working on better grades, and in these cases alternating-current can be used for variable speed work. So the element of first cost enters into the discussion and is to be balanced by the quality of the output of the mill.

Power-factor is another factor which is becoming increasingly important, due to rapid growth in the use of central station power. This can be taken care of by means of a synchronous motor, which gives a logical solution to the whole situation. By the use of a synchronous-motor, direct-current generator set, high power-factor can be obtained for the mill as well as direct-current for the adjustable-speed machines. Therefore it is easily and logically possible to derive the benefits of the squirrel-cage induction motor for the constant-speed machinery and direct-current for the adjustable at a relatively low first cost for, in determining the size of the motor-generator set (direct-current end only), load factor should be taken into consideration. In a recent installation, approximately 550 hp in direct-current motors driving printing machines and tenters are run by a 200 kw generator.

This applies as well to the mill with its own prime movers, for better power-factor at the switchboard means increased capacity of the main generator available for driving squirrel-cage induction motors. Assume a 1500 kv-a generator driving alternating-current motors and a 200 kw synchronous motor-generator set for adjustable-speed motors. With a plant power-factor of 73 percent, the generator output is 1100 kw, and if this is raised to 90 percent the output is 1350 kw. Then, taking into consideration the losses in the motor-generator set, about 30-kw, there remains a surplus of about 220 kw.

As before mentioned, the two principal types of machines requiring adjustable-speed are the printing

machines and tenters, and these should be considered separately. Before the advantages of electricity were available, the method of driving the former was by an inclined type of steam engine which drove directly each machine and was controlled by opening or closing the throttle valve. Aside from being cumbersome,

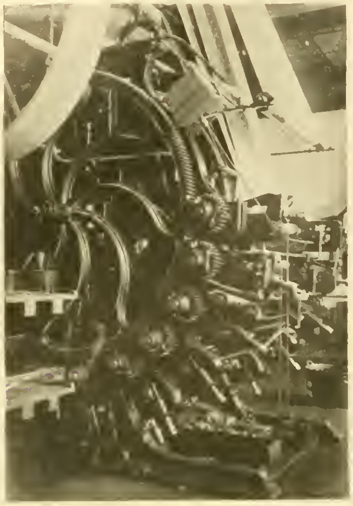

FIG. 1—PUSH BUTTON CONTROL STATION AND SPEED MASTER SWITCH MOUNTED ON PRINTING MACHINE

very poor speed regulation was obtained and all the disadvantages of running long steam supply pipes prevailed.

In applying motors, various ways can be used to drive the main shaft of the machine, depending on the space available or whether gears, chains or belts are desired. The controller is really the heart of a successful printing machine and should cater to the inherent features found in its construction. The printer should be able to give his undivided attention to adjusting the rolls and seeing that they register properly, and therefore all processes of starting, stopping and changing speeds should be done with as little effort or attention on his part as possible; this can be met only by a full automatic contactor controller, with the push-button station and speed control master switch placed on the machine itself. The inertia and starting friction of one of these machines is high and therefore suitable means must be provided to supply enough voltage to the motor armature to cause the motor to start whenever the *start* button is depressed. This is taken care of by a high-torque relay which cuts out part of the resistance for a few seconds only, by action of the motor current. Also full automatic acceleration from zero to any speed is taken care of by fluttering-type relays, which give an even increase in speed, without throwing the rolls out of register or breaking the cloth.

Motors with a speed range, by field control, of 3 to 1, and with provision for three armature points of control have been found to give the most satisfactory results. The armature points give 8, 16 and 24 percent approximately and the field points from 33 to 100 percent of maximum speed, in about 30 steps. Any of these speeds are obtained from the speed master switch; the *start* and *slow* buttons always give 16 percent speed regardless of the setting of the speed master switch. The push-button station also gives an *inch* or jog button and a *fast* button, the latter bringing the motor up to a speed corresponding to the setting of the speed master switch. All of these functions are obtained from a three-button, push-button station and speed master switch, as shown in Fig. 1. The push-button station is mounted on a nip of the machine, with the handle of the speed master switch brought, by a removable extension, within six inches of it, so that the printer has full control of his machine without turning or moving from his position in front of it. In this case the motor is placed on the mezzanine floor overhead, is belted to the main shaft and the controller in a dust proof cover and resistors are mounted close beside it, thus saving wiring and space. Fig 2 shows this equipment and Fig. 3 is a front view of the automatic control panel.

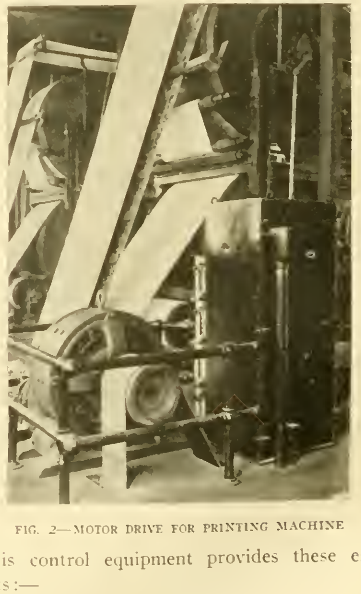

FIG. 2—MOTOR DRIVE FOR PRINTING MACHINE

This control equipment provides these essential elements:—

Quick and easy speed adjustment.
Long life of contacts.
High torque for starting.
Overload protection with relay.
No-voltage protection.
Dynamic braking for quick stopping.
Fool proof operation.
Operator's entire time available for his machine.

It is really remarkable to note the ease with which a printer can control one of these large machines with this control, for a fifteen color print machine, with its

numerous dry cans, is a bulky mechanism and covers much floor space, and both quality and quantity of production are bettered by this type of drive.

Tenters offer other possibilities for the profitable use of motors and automatic control, but here the conditions are slightly different, as the fine adjustments of speed are not so important and only one armature point is necessary for starting the material through the tenter. Hence alternating or direct-current motors are adaptable though, on the whole, direct-current is to be preferred. As the cloth is usually run through a starch or water mangle and then over dry cans before entering the tenter, these three machines can be run by one motor or by three separate ones. Even four or five can be operated in tandem and all the motors controlled from one station, and this method of control is very flexible and easily operated. Either a drum or the full automatic type of control can be used, but the advantages of the latter are evident here as elsewhere.

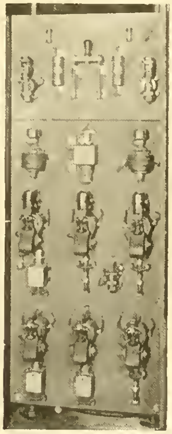

FIG. 3—AUTOMATIC CONTROL PANEL

It is fool proof, requires less upkeep cost and changes in speed are more easily accomplished.

In running two or more motors in tandem, some means must be used to keep the relative speeds the same, otherwise the cloth will either be broken or piled up between the machines. To accomplish this, a dancer roll is connected by a chain over pulleys to an auxiliary field rheostat. This dancer roll is supported by the cloth as it comes out of the first machine, say the mangle, and is free to move up and down. It is evident then that if the mangle motor runs a little too fast, the dancer roll will drop and this then cuts out some resistance and the motor slows down a little to a point where equilibrium obtains. The main field rheostats for each motor are either coupled together and moved by one handle or a special two or more section rheostat is made with one section for each motor and means provided for varying the resistance in each field circuit together, thus changing the speed of all motors together as desired. The dancer roll rheostat for each motor is in series with the main rheostat. One less dancer roll equipment than the number of motors in tandem is all that is necessary—thus in a three-motor tandem outfit, two motors only need be kept in unison with the third.

A push-button station providing *Stop, Start, Inch, Slow, Fast* with an automatic controller for each motor and a safety stop station completes the equipment. Automatic acceleration easily and gradually starts the motors to the field rheostat setting by means of special fluttering type relays and the dancer rolls then keep all motors running uniformly. Fig. 4 shows the push-button station with the main field rheostat underneath at the delivery end of a tenter.

As it is sometimes necessary in a growing mill to relocate machines, it is better to keep the controller for each motor in a separate unit and it can then easily be moved and made part of any tandem outfit or run separately with its own push button station. This flexibility is not possible when a drum controller is used with one set of starting resistance for all the motors in a tandem unit. Also a drum controller has the disadvantage that long runs of the leads from each motor are necessary, instead of the small wires required for push buttons.

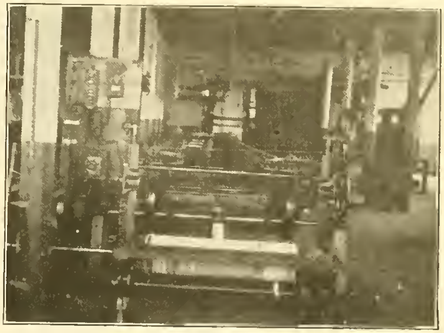

FIG 4—PUSH BUTTON CONTROL STATION WITH SPEED CONTROL RHEOSTAT FOR A TENTER

Generally speaking, the decided trend in the textile, as in other industries, is to the use of automatic control, embodying as it does so admirably, the rolling type of contact, which outlasts many times the old sliding contacts; magnetic blowouts to extinguish the arc; overload and no-voltage protection features and, not the least by any means, the ability to stand up under the hardest kind of service without any chance of an inexperienced operator damaging any part of the equipment, in other words it is practically fool proof.

Rapid strides have been made in recent years in the development of electrical apparatus to meet the exacting needs of finishing plants, but it is not easy to conceive of new improvements, which will replace the commutating-pole, adjustable-speed, direct-current motor with push-button automatic control, for those machines requiring speed adjustment.

Silk Throwing and Electric Drive

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RAW silk is the product of the silk worm, which at the close of its life of about two months, spins itself up into a cocoon, the layers of which constitute a filament measuring from 0.0003 to 0.0008 inches in diameter and from 300 to 8000 yards in length and requiring about 1000 miles to make up one pound of silk. The first step necessary to get the silk into workable size is to soften these cocoons in hot water to make the filaments unravel readily, and also to soften the gum or silk glue, called sericin. Five or more of these cocoon filaments are brought together and caused to twine around each other while the sericin is soft and sticky when they become agglutinated into one compact thread and reeled up into skeins of from 40 000 to 50 000 yards. A five cocoon silk has about 300 000 yards to a pound and measures about 0.0022 inches in diameter. The breaking strength of a five cocoon thread is about 60 grams, the elasticity from 15 to 20 percent depending largely upon humid air conditions. About 20 percent of the thread is sericin or silk glue and 80 percent real fibre. The sericin becomes hard and brittle under a dry atmosphere and to get good spinning results the thread must be rendered pliable either by a moist atmosphere or treating with an emulsion of soap and oil.

Reeling is done largely where the silk is raised, as in China and Japan, and the silk is shipped in the form of skeins packed in bales, in which form it is received by the throwing mills in this and other countries where the silk is made in-to manufactured articles.

THROWING OR SPINNING

The process of silk throwing or spinning is twisting, doubling and re-twisting the silk from the skein into yarn of the desired size and strength for use in the manufacturing processes, such as knitting and weaving. The process is analogous to cotton twisting although the machines used are called spinners.

The first step, called winding, is to transfer the silk from the skeins on to spools for the spinners. The different operations of throwing are called winding, first time spinning, second time spinning, doubling, twisting and reeling. Each may be performed on separate machines, although in some cases two or three processes are combined and accomplished on the same machine. In the first time spinning, the single thread is placed on the spinning spindle and given a certain amount of twist. In the second time spinning two or more of these threads are twisted together making a thread proportionately larger. Doubling is the process of bringing two or more threads together as one thread; on the 5-B combination spinner and doubler it is given from 2 to 3.5 turns per inch. When more twists are wanted this is added on the second time spinner.

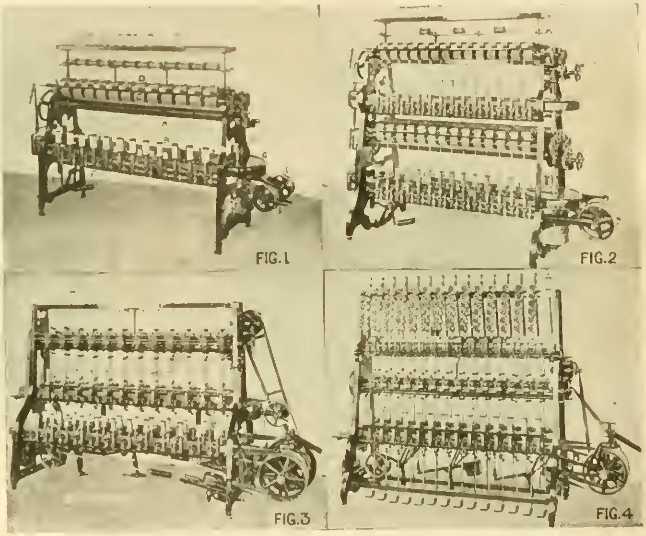

FIG. 1—SINGLE DECK SILK SPINNER
FIG. 2—DOUBLE DECK SILK SPINNER
FIG. 3—COMBINATION SPINNING, DOUBLING AND TWISTING MACHINE FOR SILK
FIG. 4—COMBINATION DOUBLING AND SPINNING MACHINE FOR SILK

THE SPINNER

The essential parts of the spinner are shown in Fig. 1. *A* are the vertical steel spindles which carry the bobbins *B* containing the silk to be spun. *C* are the take-up rolls which take the spun silk and feed it to the receiving spool *D* upon which it is wound. The spindles are driven by a belt *E* which runs in contact with the whirl *F* of the spindle. The spindle belt *E* is driven by the pulley *G* on the vertical shaft *H* which in turn is driven by a belt from a line shaft over-head through the idle pulleys *I* and the driven pulley *J* on

the vertical shaft. The speed of the spindles ranges from 6000 to 14 000 r.p.m., depending upon the class of spinning to be done and the style of machine used.

Four styles of spinners are in general use according to the number of operations to be performed.

1—A single-deck spinner is shown in Fig. 1. The term single deck refers to a set (two rows) of spindles, one on

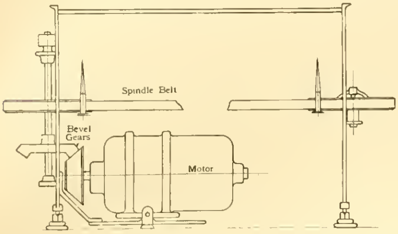

FIG. 5—OLD METHOD OF DRIVING SILK SPINNERS WITH HORIZONTAL MOTOR AND BEVEL GEARS

each side of the machine, located in the same horizontal plane. This style of spinner may be used for either first or second time spinning.

2—A double-deck spinner is shown in Fig. 2. "Double-deck" refers to two double rows of spindles, the one located directly above the other. This machine may be used for either first time, second time or both first and second time spinning. In the latter case the first and second time spinning is one continuous process.

3—A combination spinning, doubling and twisting frame is shown in Fig. 3. This is also a double-deck machine with two rows of spindles on each side of the lower deck and one row on each side of the upper deck. The silk spun on each two of the spindles on one side of the machine passes through a common guide eye to the feed rolls at the top of the machine, from which it is fed to a single spindle on the side of the machine on the upper deck. This spindle gives the final twist to the two strands, thus making the completed yarn and winding it on to the bobbin on this spindle.

4—Combined doubling and spinning for tram is shown in Fig. 4. This is also a single-deck spinner. Two threads are taken from the spools at the top of the machine and pass through the rolls at the center of the machine, where

FIG. 7—STANDARD VERTICAL 1760 R. P. M. MOTOR DRIVING A SINGLE DECK SPINNER

The spindle belt is driven direct from the motor pulley.

the threads are doubled, then taken to the spindle on the lower deck where the thread is spun or given the proper amount of twist.

ELECTRIC DRIVE

The original method of drive for these machines was by belt from the mill line shafting.

The next step was to eliminate the line shaft with its belt drive to the machine and drive each spinner by a single motor. Various forms of drive have been tried. One of the first was that of a horizontal motor placed on the floor or on a bracket and driving with bevel gears to the vertical shaft of the spinner, as

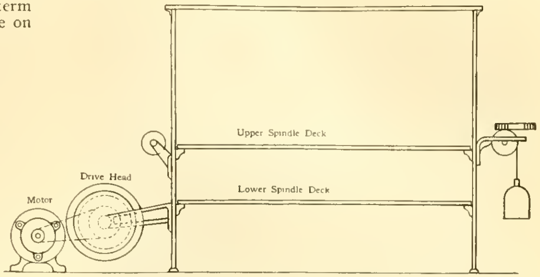

FIG. 6—COMBINATION SPINNING, DOUBLING AND TWISTING MACHINE DRIVEN BY A HORIZONTAL MOTOR

shown in Fig. 5. The disadvantages of this form of drive were noise, inefficiency and the excessive wear of the bevel gears.

Another form was to place the motor on the floor and connect it by a belt or chain direct to the cross head shaft of the machine, as shown in Fig. 6. The disadvantage of this form is that it takes up valuable floor space, and retains the crosshead drive with its quarter-turn spindle belt.

Single and Double-Deck Spinners—A new and effective method of drive applied to either a single-deck or double-deck spinner is that of a vertical motor having a shaft extension and pulley at the top for the single-deck spinner and a shaft extension at both top and bottom with pulleys for the double-deck spinner and driving direct

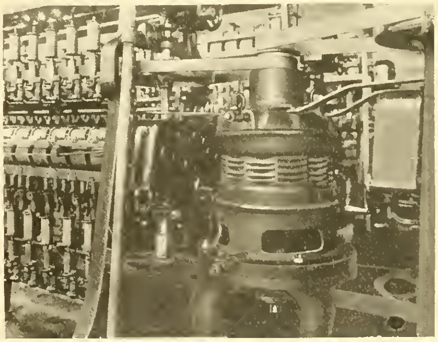

FIG. 8—TWO DOUBLE DECK SILK SPINNERS DRIVEN BY A 1760 R. P. M. VERTICAL MOTOR

on to the spindle belts. Fig. 7 shows this method, using a standard vertical motor mounted on the floor and driving a single-deck spinner. Belt tension for the spindle belt is taken care of by weight and rack at the opposite end, being part of the machine furnished by the machinery builder. This form represents by far the simplest and easiest method of driving these ma-

chines. It eliminates the vertical belt drive from the line shaft down to the machine together with the brackets and idlers for this belt and the driven pulleys on the vertical shaft. The motor takes up about the same space as the brackets and idlers at this end of

FIG. 9—STANDARD VERTICAL 870 R. P. M. MOTOR DRIVING A SINGLE DECK SILK SPINNER

the machine, hence no additional floor space is required, nor are any changes necessary on the spinner.

Two single-deck spinners can be driven by the same type of motor, mounted between them. The spindle belts are driven from a double flanged pulley at the top of the motor, one spinner being raised two inches above the level of the other to accommodate this drive. This method has the advantage of saving a total of about three feet of floor space at the ends of the machine. A similar drive is used with the narrow

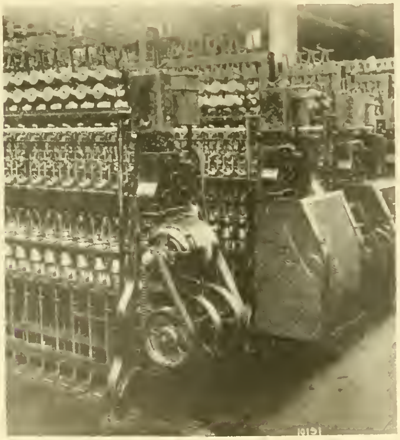

FIG. 10—STANDARD HORIZONTAL MOTOR DRIVING A COMBINATION DOUBLER AND SPINNER

type of spinner, two idler pulleys being placed on the outside of the end stand, one on each side of the spindle belt, to give this belt wrap enough to drive the take-up pulley.

Fig. 8 shows a standard vertical motor driving two double-deck spinners. The motor has a shaft extension on both top and bottom ends and drives direct onto the spindle belts. This same form of drive may be applied to one spinner. One frame is raised two inches above the level of the other in order to accommodate the double flanged pulleys on the motor. This drive has the advantage of saving considerable floor space.

Direct Connected Motor—The latest and most compact form of drive for the wide single and double-deck machines is that of a motor mounted central with the vertical shaft of the spinner and coupled to it, as shown in Fig. 9. The lower bracket of the motor serves as the mounting base for the end stand of the

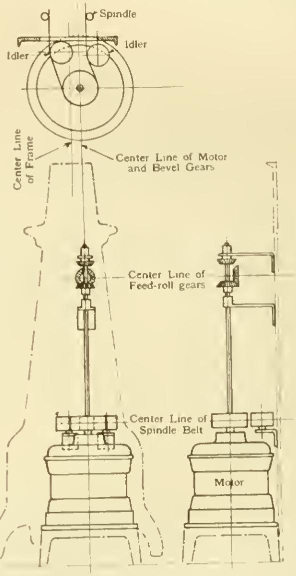

FIG. 11—STANDARD VERTICAL MOTOR DRIVING A COMBINATION DOUBLER AND SPINNER

spinner, and the vertical shaft which drives the take-up gears is inserted in the hub of the spindle belt pulley, which serves as a coupling, thus assuring perfect alignment with the motor shaft. The motor is self contained with the machine, and as the motor rests on its broad base mounted on the floor the whole gives a very rigid support. To install this motor it is only necessary to cut out the cross web at the lower part of the end stand to admit the motor, insert the studs on the feet of the end stand into the motor bracket, and cut off the vertical shaft to the proper length to fit into the spindle belt pulley. Brackets, idlers and driven pulleys provided for belt drive may be removed.

In the case of new machines the end stand of the frame may be furnished with the lower web omitted, also omitting the brackets and idlers and driven pulleys required for belt drive. This form of drive is compact and stable, requiring practically no changes on the

machine. The motor and base do not extend beyond the guard of the spindle belt pulley, the drive takes up less floor space then any other yet designed, and no additional safety guards are required for the motor.

Combined Doubler and Spinner for Tram—Two methods of drive are used for this spinner. In one method a motor is bolted to the end stand of the frame just above the cross head, connected by chain to a sprocket on the overhung shaft of the cross head, as shown in Fig. 10. Wire screen guards are placed over the motor and cross head, thus insuring complete safety for operators. In the other method a standard vertical motor is placed on the floor or on a bracket immediately outside of the end stand of the frame, driving the spindle belt direct from a shaft extension and pulley at the top of the motor, as shown in Fig. 11. The feed is driven by a vertical shaft coupled to the motor shaft through bevel gears at the top. This method gives a compact and simple drive, eliminating the cross head with its pulleys, brackets, quarter turn belt, as well as the pulleys, belts, and bevel gears required to drive the feed.

Day and Night Lighting in Textile Mills

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SELDOM does the person in charge of the lighting of a textile mill have sufficient facilities to know what it is that he is buying. He purchases "lighting fixtures"—lamps, reflectors, hangers, and his investment in such equipment is far too frequently gaged solely by the first cost of that equipment, or by the cost of the electrical power to operate the lamps. Perhaps he assists in the design of a new mill building and in the placing of the machines; but for the daylight illumination overlooks the fact that to secure usable daylight he must expend thought and seek experience, for windows can seriously hinder as well as aid production and vision. Moreover, it frequently costs as much to operate the glazed areas as it does to operate incandescent lamps!

In the first place, in mill lighting, we should seek to buy a result and not an article of equipment. We should purchase and evaluate actual resultant illumination, and not merely glassware and metal. We must know and buy useful illumination, and we must base our operating cost of lighting upon "dollars per foot-candle or lumen"—not upon "dollars per outlet or per fixture." For example, a purchaser of coal for a large industrial establishment does not buy merely so many tons of a black substance, and be satisfied if the coal is merely black in color, and of certain sized lumps He purchases coal of a specified heating value, and which has a specified percentage of ash and definite clinkering qualities,—i. e., he really purchases a usable heating or steam making ability. And so it should be with illumination, either natural or artificial. It is ability to see, and illumination on the work, that should be the first consideration, and the only measure of true efficiency in lighting a mill is "how much per unit of useful light," not what is the price of the lamps, glassware and accessories.

Every textile mill operator would like to know whether his lighting system is more, or less, efficient than that of his neighbor. To obtain any knowledge of lighting economics, one must have a common measure of the light, and this would be simple if it were as easy for a mill manager to think in terms of lumens of light as it is to think of quarts of water, pounds of steam, or yards of silk. Yet there is nothing complex about knowing or measuring this item called illumination. Suppose we substitute—in imagination—a cloudy sky for the ceiling of the factory, and also imagine a fall of snow from that cloud. If the snow accumulates on the floor to a certain thickness, we place a yard-stick vertically into it, and by measuring, we might say it is one foot thick. Now if light were

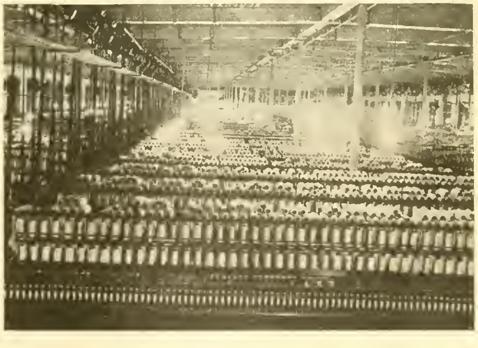


FIG. 1—A POOR LIGHTING INSTALLATION IN A SPINNING ROOM

The bare lamps on drop cords suspended close to the operators' eyes produce a glare and cause harmful effects to the eye sight.

allowed to fall upon the floor from overhead lamps, we could similarly measure the thickness of "light-fall" by using not a yard-stick this time, but a foot-candle meter and, whereas the thickness of snow-fall might be a certain number of feet, the thickness of light-fall (or the value of horizontal illumination) would be a certain number of foot-candles.

Carrying out the same analogy, in order to evaluate the quantity of snow on the floor, we naturally would measure the area covered, and multiply that area by the thickness of snow, thereby ascertaining the

cubic feet of snow. To know the quantity of useful illumination we multiply in exactly the same manner, the area illuminated by the foot-candles of illumination falling upon that area or surface, and get a new unit which cannot be called quarts, cubic feet, or bushels of light, but which we call "lumens" of light.

It is not difficult to get a true measure of lighting costs, by evaluating it in cents per lumen, just as we would evaluate wheat in dollars per bushel. Keeping in mind this fundamental conception of illumination, we can note profitably some of the cardinal points governing textile mill lighting, summed up as follows:

1—The laws that are in force to protect workmen against inability to see and to afford them self-protection, require not less than two foot-candles of illumination for moderate or average work, and not less than three foot-candles for close discrimination of detail. These are minimum values, and it is usually profitable to exceed them materially.

2—Bare lamps, especially of the gas filled or Mazda C types, when hung low, as on drop cords, or placed in the field of vision, are prima facie evidence

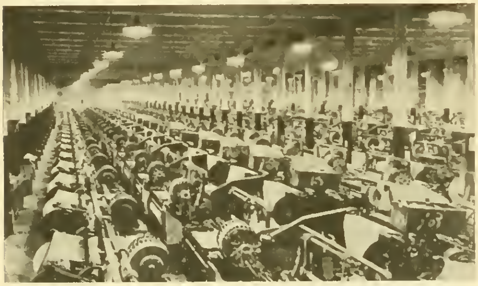


FIG. 2—MODERN GENERAL LIGHTING OF A COTTON MILL

of reckless waste of light and of detrimental glare. Such a spinning room as shown in Fig. 1 is poorly lighted, and the contrast between it and Figs. 2 or 3 demonstrates conclusively the superiority of an installation using shaded overhead lighting units.

3—The shallow dome or flat metal reflectors are obsolete as far as their proper use for general overhead lighting is concerned, and the most modern and efficient reflectors for use with bowl-enameled Mazda C lamps are of the RLM shape, the angle type, or the deep bowl shape. There is no gain in using the deep bowl metal reflectors in place of the RLM, except where it is desirable to shade the lamp filament more completely from direct view.

4—Elimination of glare is more than a matter of comfort, it is a distinst move towards economy. Any photographer who points a camera towards the sun in taking a picture, would expect a fogged plate; any workman facing a bare lamp will get blurred images of the machinery or textiles that he is straining to see.

5—Light colored interiors are valuable aids to lighting. One typical mill increased the illumination 25 percent by an application of white paint to the ceiling. Paying good money for the generation of light, and then allowing it to be absorbed by dark, smoky walls and ceilings seems as illogical as to build water

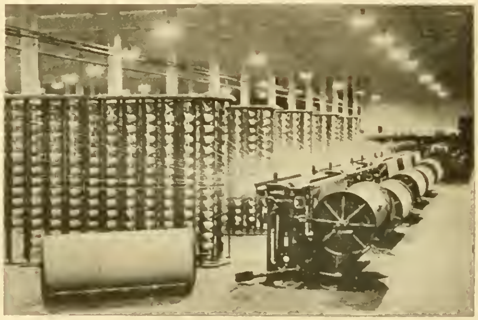


FIG. 3—PROPER ILLUMINATION ALLOWS EACH THREAD TO BE SEEN

reservoirs of sand and allow the water to soak away into the earth.

6—The frequent cleaning of textile mill lighting equipment is especially necessary, because lint, dust and oil vapors accumulate upon lamp bulbs and reflector surfaces to such an extent that the efficiency of the system falls to 75 percent or less of its initial output, after two or three weeks of neglect. When washing lighting equipment, it is important to remove all soapy solutions or films, lest dust adhere to such invisible films. One should dry reflectors carefully, preferably with tissue paper. It is a good plan to have a lamp rack, similar to that shown in Fig. 4, in the stock room, so that the maintenance man can therewith more easily take out new, and bring back old lamps.

7—Do not forget that Mazda lamps must be burned at their rated voltage in order to produce light most economically. The candle-power of a lamp falls off rapidly as the operating voltage is reduced. Lamps rated at 110 volts and burned on circuits that actually

FIG. 4—A LAMP CARRYING RACK FOR CLEANING AND MAINTENANCE

measure 105 volts at the sockets, are producing only 85 percent of their rated amount of light.

8—Lighting units for general overhead or broadcast illumination should be connected in rows parallel

to the windows, so that the failing daylight, evidenced by darkness occurring first down the center of the room may be supplemented by artificial light only where needed.

9—Natural daylight falls in value very rapidly as one moves away from the windows. Fig. 5 illustrates

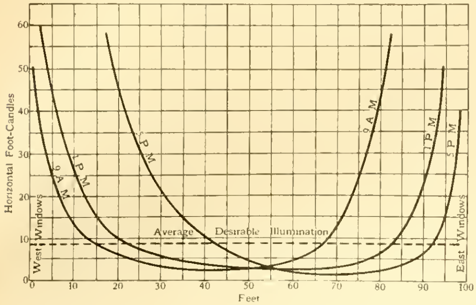


FIG. 5—CHANGES IN DAYLIGHT ILLUMINATION WITHIN A FACTORY THROUGHOUT A JUNE DAY

The building extends north and south, has a 16 ft. white ceiling and the walls are 60 percent clear glass.

this fact, and shows as well that the natural daylight within a room changes greatly from hour to hour. The east side of a mill needs artificial light to supplement daylight in the late afternoon; the west side needs artificial light in the morning.

10—The color of daylight changes from hour to hour. Fig. 6 shows that afternoon sunlight is relatively low in its percentage of violets, blues, and greens, but high in reds as compared to north skylight. Textile work that involves color matching is influenced by this fact, and hence daylight cannot be depended upon as a color standard.

Taking up the most important parts of a textile mill, place by place, it is well to note the results of a number of operators' experiences as follows:—

Cotton Carding and Drawing—Detailed vision is not essential, and broadcast general illumination is suf-

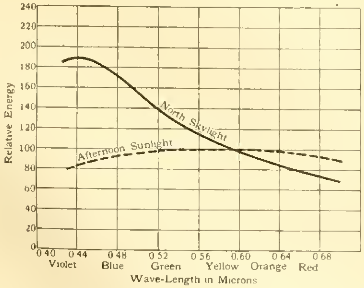


FIG. 6—CHANGEABLE COLOR QUALITY OF DAYLIGHT

ficient. Small individual drop lights are being discontinued, and modern mills are now using 1.5 to 3.0 foot-candles, from metal dome reflectors hung at about 10 feet, spaced on 20 to 25 foot centers, and equipped with 150 watt lamps.

Spinning Frames, Twisters, Spoolers—More illumination is required, as the threads become successively smaller. Up to the finer work it is well to increase the illumination to 5 to 8 foot-candles, meaning about 1.5 watts per square foot of floor area.

Warpers—Fig. 3 shows a system to take care of this class of work. Individual threads must be visible, which means an installation of at least 75 watts per machine. Not only must the light fall on horizontal surfaces, but on inclined surfaces as well.

Looms—Shadows are the chief fault of the lighting of looms. Two general arrangements of outlets have been used, as shown in Fig. 7. Plan *A* involves less wiring costs and, unless the frames are high, or the ceilings low, this arrangement results in excellent illumination. The lighting is usually about four foot-candles in the shadows, and twice that value outside the shadows. In silk weaving it is necessary to see and tie broken threads, and whereas a local lamp hung close to the work will enable the operator to do this, yet at least the same wattage is required as would

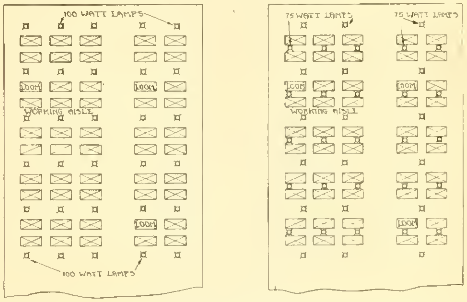


FIG. 7—TYPICAL PLACING OF OUTLETS FOR THE LIGHTING OF LOOMS

Plan *A*—50 watts per loom. Plan *B*—60 to 75 watts per loom

be necessary with a smaller number of larger overhead lamps, and the operating, maintenance and wiring costs are no less. For example, the mill now using Plan *A*, Fig. 7, formerly had a 60 watt (620 lumen) lamp hung over each machine. The new arrangement requires only 50 watts per loom, yet the lumens per machine are increased from 620 to 650.

Most of the present textile mill lighting installations are relics of the practice of carbon filament lamp days, or else have, under the stress of war conditions, been made without regard to true economical maintenance. Like Topsy, they "just grew". But bigger profits to both owners and workmen must grow from lower output costs, and hence it is that the item of lighting is now receiving close study, tending toward the elimination of waste light, the use of more efficient devices and the installation of systems that will, in addition to providing merely some light, really result in quick, easy, ample vision.

THE ELECTRIC JOURNAL

OPERATING DATA FOR CONVERTING SUBSTATIONS

NOVEMBER 1921

Transformers for Synchronous Converters

Transformers are required for stepping the voltage of the transmission circuit down to a suitable value for the alternating-current windings of the synchronous converters used to supply the direct current for driving railway equipment. They may be either single-phase or three-phase units, oil-insulated self-cooled, oil-insulated water-cooled or air-blast. These types are commonly referred to as OISC, OIWC and AB. OISC and OIWC units may be shipped assembled in the cases, either with or without oil, or the core and coils may be boxed and shipped separately.

Where the transformers are shipped completely assembled, unpacking consists of simply removing the boxing or bracing. If the core and coils are shipped separately from the case, they should be left in the packing cases until the transformer tanks have been placed in position and made ready to receive the active elements. This procedure will afford mechanical protection and prevent undue absorption of moisture by the insulation. In all cases it is very essential that the windings be protected from dampness or sudden changes in the temperature of the

FIG. 1 SHELL TYPE TRANSFORMER

air, which may cause sweating. An accumulation of moisture similar to that which collects on a pitcher of ice water on a summer day is likely to form on the unpacked core and coils if they are brought directly from a cool store room into a warm substation.

Air blast transformers should be given protection against exposure to dampness, both before installation and after being put in service.

With all types of transformers, a careful inspection should be made after the boxing has been removed, to make sure that no mechanical injury has been sustained during transportation. This should include internal as well as external examination, and should cover such points as proper centering of the core and coils in the case, suitable spacing between adjacent leads from coils to terminal block, checking to make sure that bolts and nuts are tight, and search for any foreign substances, such as nails from the crating.

When the transformer has been shipped in oil, it is usually not necessary to dry the windings. In such cases a number of samples of the oil should be drawn from the bottom of the case and tested. If these tests indicate that the oil is in good condition and the foregoing instructions have been followed, the transformer may be put in service. Should there be moisture in the oil, it should be drawn off and dehydrated. The insulation must also be tested and if it fails to show sufficient strength, the transformer must be dried out, after which the dehydrated oil should be put back into the transformer case with the least possible delay.

Where shipment has been made without the oil, or if the transformers are air-blast, it is necessary to make tests of the insulation resistance. If these tests indicate a low value of resistance, drying out must be resorted to and maintained until sufficient insulation strength is shown.

After the transformer is ready to put into service, it is recommended that it be brought up to its normal operating voltage slowly, so that any error in connections, or other trouble, may be discovered before damage is done. After operation at full voltage for a few hours, load may be applied. A close check on temperature should be made during the first few hours under load, and any indications of undue rise promptly investigated.

OISC transformers are so designed that they will operate at their rated loads without exceeding a safe temperature, provided the temperature of the ambient air does not exceed 40 degrees C. and the oil level is maintained at the proper height.

The cooling of OIWC transformers is dependent upon the circulation of a specified amount of water through the cooling coils. The amount required is given either on the name

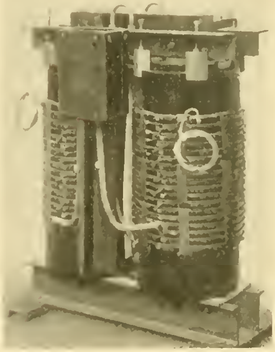


FIG. 2 CORE TYPE TRANSFORMER

plate or on the diagram of connections. Where there are two or more parallel sections of the cooling coil, the valves should be arranged so that each section shows approximately the same flow of water. When the proper setting has been determined the valves should be marked and in shutting off the cooling water only the main valve should be closed.

Air-blast transformers require a definite volume of air per minute delivered through the base of the housing at a static pressure sufficient to overcome the friction in the cooling ducts within the transformer. The volume and pressure required are given either on the name plate or on the diagram of connections. A damper is provided to regulate the flow of air. This should always be kept closed when the transformers are not in service. A screen of approximately 3/8 in. mesh should be provided over the air intake. As this will require frequent cleaning it should be arranged so that it can easily be removed.

It is apparent from the foregoing that the OISC. type is more easily installed and requires less care in operation than either of the other types. However, the OIWC. type is considerably cheaper in first cost than the OISC., especially in units of comparatively large rating.

In some districts the restrictions of the underwriters are such as to make the cost of installing oil-insulated apparatus prohibitive. In such cases air-blast construction is used. OISC and OIWC types can be built for any supply voltage, but air-blast transformers are not used for potentials in excess of 25000 volts..

E. R. SAMPSON

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

2047—OVER EXCITED SYNCHRONOUS MOTOR—I have difficulty in explaining the physics involved in the synchronous motor. It can be shown analytically and verified by experiment that sufficient over-excitation of a synchronous motor causes the motor to fail to carry its load. The torque of a synchronous motor is some function of the product of the armature pole strength and the rotor pole strength. Over excitation causes the armature current of a synchronous motor to increase above the value it would have if the motor operated at unity power factor. An increase in the armature current surely means an increase in the armature pole strength and over excitation means that the rotor poles at least have a tendency to increase in strength. I don't see physically why an over excited synchronous motor refuses to furnish the necessary torque to keep it going.

R. E. B. (PA.)

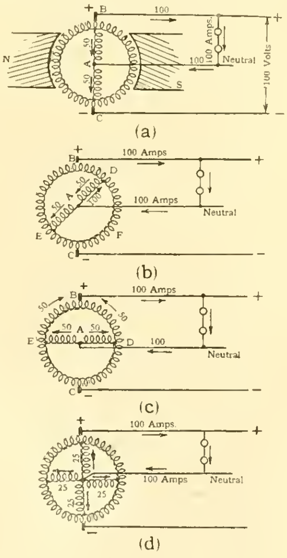
Throughout the normal operating ranges of a synchronous motor, increasing the excitation always increases the maximum available, or pull-out torque; as an explanation we refer you to an article on "Principles and Characteristics of Synchronous Motors" in the JOURNAL for March 1921, p. 87. Greatly in excess of the operating limits, which is perhaps to what you refer, there are two factors which may cause a decrease in torque—first, saturation of the poles; second, the effect of armature resistance. When the poles saturate, the field m. m. f. is used up in forcing the flux, which becomes largely leakage, through the rotor and poles. In the case of the armature resistance the input increases as the first power of the in-phase component while the I^2R loss, of course, increases as the square of the current. It can be readily seen that if the current increases indefinitely, say 50 times normal current or more, the I^2R loss may consume the whole input to the motor. This latter is the physical explanation of those mathematical diagrams which show the effect to which you refer.

E. B. S.

2048—THREE-WIRE GENERATORS— We have installed four three-wire electric generators, with ratings of 75 kw, 110 kw, and 150 kw. The 110 kw machine has one balance coil, the others, two coils each. We are desirous of finding out exactly how the unbalanced current divides in the balance coils, whether it divides equally at all times, or whether it goes through a perodic change. We need a simplified explanation of the balance coil action for the benefit of the students, as we have been unable to find a clear explanation in any available text book.

C. K. (VA.)

The unbalanced current of a three wire direct-current generator divides equally in the balance coils. In the case of a single-phase balance coil, the neutral line is connected to the center of the balance coil and the unbalanced current divides equally in the balance coil, one-half the current going in one direction and the other half in the opposite direction, the two tending to magnetize in opposite direction. If this was not the case, the magnetization of the balance coil, which may be considered simply as a transformer, would be unbalanced. In addition to the unbalanced current flowing in the balanced coil there is superimposed on it a small alternating current required for magnetizing the balance coil and generating the necessary counter e.m.f. Fig. a shows a single-phase balance coil, the slip rings being omitted for the



FIGS. 2048 (a), (b), (c) and (d).

sake of simplicity, with the armature in a position such that the balance coil connection lies directly under the commutator brushes. In this position the balance coil has the maximum voltage across its terminals, i. e. a voltage equal to the direct current voltage on the outside wires of the line. The center point of the balance coil A is clearly at a voltage= $\frac{E.\ C.\ Terminal\ Voltage}{2}$ above and below — and + brushes respectively. Assume an out of balance current of 100 amperes in the + and neutral leads and zero current in the — lead, the balance coil may then be considered purely as an autotransformer with an instantaneous value of 100 volts impressed on its terminals and having 50 volts from A to B and A to C. The unbalanced current of 100 amperes is circulated through the + and neutral wires by the voltage from A to B, the current in the balance coil A B being 100 amperes. The balance coil acting as an autotransformer then requires a primary current of 50 amperes flowing through the balance coil from B to C to balance a load current of 100 amperes minus the unbalanced load in the external circuit flowing from A to B. This is exactly the principle of an auto transformer which pulls a balancing current of 50 amperes from its source of supply completely through the balance coil to balance a load current of 100 amperes taken from its middle point and one of its terminals. This is obviously necessary so that the load ampere turns of the primary balance the load ampere turns of the secondary. The resulting current flowing in the halves of the balance coils are then A to B 100 amperes and B to A, 50 amperes giving 50 amperes resultant current, and A to C 50 amperes resultant current. Thus, the resultant is an equal division of the unbalanced load current, one-half flowing from A to B and one-half from A to C. In Fig. b the position of the balance coil is shown when advanced one-eighth of a revolution. For the sake of simplicity, assume that the armature has the induced voltage in its coils evenly distributed from B to C. Then point E will be 25 volts above C, and D will be 75 volts above C. The impressed voltage across the balance current terminals E and D will be 75—25=50 volts with point A 50/2=25 volts above and below points E and D respectively. Thus, the voltage from A to B through D is 25 + 25 = 50 volts, and from A to B through E is 75 — 25 = 50. The balance coil still acts as an autotransformer with the same action as shown in Fig. (a) and still has the resultant currents of 50 amperes from A to D and from A to E. The distribution of the currents in the armature split up in accordance with the relative resistance of the circuits EB, EFD and DB. In Fig. (c) the balance coil is shown in a position half way between the brushes. In this case there is zero voltage impressed on the balance coil terminals E and D and points E, D and A are all 50 volts above and below C and B respectively. In this case it is clear that the distribution of the current is as shown in Fig. (c). A three phase or a four-phase arrangement is similar in action to the single-phase arrangement described above. The distribution of the unbalance load current, being always equally divided in the balance coils. See Fig. (d) for two phase or double single-phase arrangement having two balance coils.

H. E. S.

2049—COMPOUNDING GENERATORS— Why are some compound generators and motors connected so that the series

field opposes that of the shunt and on others it assists? G. W. S. (CALIF.)

A direct-current generators that is shunt wound inherently has a drooping voltage characteristic, i. e., the terminal voltage of the machine drops off as the load increases. This is a result of the internal resistance drop in voltage and the decrease in the resultant flux per pole caused by the armature reaction. In a generator having a cumulative compound winding, the series coils assist those of the shunt winding as the load increases, thereby compensating or overcompensating for the drop in terminal voltage caused by the internal resistance drop in voltage together with the decrease in the resultant flux per pole. This type of generator is made with one of two purposes in view:—

1—To give the effect of flat compounding over a definite range of load, or

2—To compensate for resistance drop in voltage in the line. With a generator that has a differential compound winding, the series coils oppose those of the shunt winding, thereby making the drop in terminal voltage greater than in a shunt machine as the load increases. This type of generator is seldom used, but has been built with one of two purposes in view:—

1—To cause the terminal voltage to drop in a definite manner as the load is increased, or

2—To supply constant current to an external circuit of variable resistance.

Motors that are likely to be stalled in service are sometimes supplied with power from a generator that has a differential compound winding so that the motor will be protected in case of excessive overload, i. e., the voltage of the generator supplying power to the motor drops to zero on excessive overloads. This is a very special application. Arc welding is an example of constant current application for this type of generator. The special feature of performance that distinguishes between series, shunt and compound motors is the speed characteristic, or the change in speed with the change in load. At constant applied voltage, this change is dependent upon the change in the resultant flux per pole as the load changes, and on the internal resistance drop in voltage. Most shunt motors inherently have a slight drooping characteristic, i. e., the speed drops off as the load increases, because of the internal resistance drop in voltage. The decrease in the resultant flux per pole, caused by armature reaction, tends to increase the speed as the load increases, but is not usually strong enough to counterbalance the effect of

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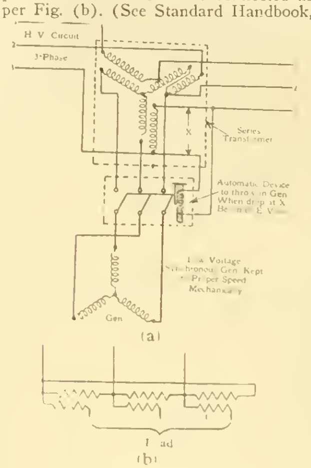
ain a constant speed characteristic, which is the one reason for using this type of motor. A motor with a differential compound winding is rarely used, because the speed of shunt motors is so nearly constant from no load to full load that the extra complication of a series winding is seldom necessary. H. B. W.

2050—Boosting Three-phase Circuit—What is the method employed for boosting a three-phase circuit. Give references as to detailed exposition on same. Is the method outlined in Fig. (a) practical? W. W. G. (WISC.)

The best way to boost the voltage circuit is by means of a three-phase induction regulator. The voltage can be boosted by means of a three phase booster transformer connected as per Fig. (b). (See Standard Handbook,

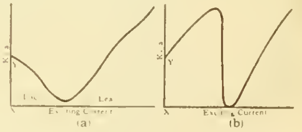


FIGS. 2050 (a) and (b)

fourth edition, pp. 1014-5). The scheme shown in Fig (a) will not work for, when the generator switch is open, the series transformer has open circuited secondaries, and would produce high reactance in series with the line. If the generator switch was kept closed and its field strength varied to give different degrees of boosting, then the scheme will operate. J. F. P.

2051—Synchronous Condenser—We have a 2000 kv-a, three-phase, 50 cycle, 3300 volt, 350 amperes, 600 r. p. m. self-starting synchronous condenser. A 126 volt, 170 ampere exciter direct coupled furnishes the exciting current. Under ordinary starting conditions, when the excited current is increased gradually, the lagging currents decrease, from starting amperes, to zero, hence leading currents increase as shown in Fig. (a). However, sometimes, quite the reverse phenomenon takes place. The lagging currents increase from the starting current of 220 amperes, simultaneously with the gradual increase of exciting current. When the lagging currents have increased to 450 amperes they take a sudden drop to zero as shown in Fig. (b). Will greatly appreciate an explanation as to what causes the reverse phenomenon. S. G (JAPAN.)

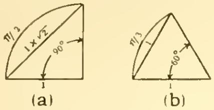
Since no value of exciting current is given in Figs. (a) and (b) it is assumed that the exciting current is zero at the kv-a axis. Then, with zero field current the machine is drawing its excitation from the line as indicated by the lagging current XY in Figs. (a) and (b). The amount of this lagging current is just enough to produce sufficient excitation (armature ampere-turns) and reactance voltage, to make the generated voltage plus the reactance voltage of the machine (neglecting I^2R drop) equal to the applied line voltage. Now, if the field is excited such that its excitation is in the same direction as the armature excitation, less armature exciting and hence, lagging current from the line will be necessary to obtain the balance between the generated voltages of the machine and the line voltage as mentioned above Further increase in the exciting current will cause the lagging armature current to continue to decrease until the point is reached when the field excitation is just sufficient to cause the machine to generate a voltage equal to the line voltage. The power-factor of the machine at this point will be unity and its armature current is a minimum. If the exciting current is increased beyond this point an excitation will be produced which is greater than necessary for the machine to generate the required counter voltage. Therefore, a leading current will be drawn from the line to oppose the field excitation and give a resultant excitation just sufficient to generate the required counter voltage. The action of the condenser in this case is as shown in Fig. (a). Now, if the machine pulls in step relative to the armature such that when the field is excited its excitation opposes that of the armature (i. e. the field is re-



FIGS. 2051 (a) and (b)

versed) more armature excitation and hence lagging current will be required for the machine to generate the necessary counter voltage. Further increase in the exciting current will tend to further decrease the excitation and more lagging current will be required to maintain a constant generated voltage. The lagging current will continue to increase with increase in exciting current, until a point is reached where the rotor lags with respect to the armature, due to the energy load required by the losses in the machine, to such an extent that it actually slips a pole with respect to the armature, i. e. it will be 180 degrees from its former position. Then the field excitation and the armature excitation will be in the same direction. Therefore, less armature excitation and hence lagging current will be required. Then further increase in exciting current will cause the lagging current to continue to decrease or, if before the machine slipped a pole, the field excitation had been increased to a point equal to or greater than that now required at unity power-factor, further increase in exciting current would cause an increase in leading current. The action of the condenser in this case corresponds to that shown in Fig. (b). The sudden change in armature current from lagging to practically zero or leading current in Fig. (b) corresponds to the point where the machine slips a pole. M. W. S.

2052—Winding Factors For Reconnecting Induction Motors—How are the winding factors obtained, used in changing an induction motor from two phase to three phase and vice versa. A two-phase motor reconnected for three phase should be run on 120 percent of normal voltage in order to give the same operating characteristics that it had before, or in other words, if run on normal voltage it will exhibit all the symptoms of a motor operating at 20 percent under voltage. Conversely, a three-phase motor rewound for two phase should be run at 75 percent of normal voltage. I am unable to see how the factors given in the above paragraph are obtained. In the following practical example I have shown the method in which I would determine these constants. Please check over my work and point out the error. Assume a motor having the following charac-



FIGS. 2052 (*a*) and (*b*)

teristics: 440 volts, two phase, 72 slots, 72 coils, 12 groups, 6 coils per group, groups connected in series. To make this motor operate on three phase, the coils are regrouped making 18 groups of 4 coils per group. Under two phase conditions 440 volts are impressed across 36 coils or the voltage per coil is 12.2 volts. If the motor is connected star for three phase, each phase will consist of 24 coils, or the voltage which could be applied to each phase would be 24 × 12.2 or 293 volts. The line voltage would therefore be 1.73 × 293 or 507 volts. From these calculations it would seem that the machine should be operated on 115 percent instead of 120 percent of normal voltage.

E. W. S. (PA.)

You have neglected the phase distribution factor, which is the factor which corrects for the different coils in series per group being slightly out of phase. Graphically this is the relation of the chord to the circumference or the approximate arc of the angle of phase belt span as shown in Figs. (a) and (b).

$$\frac{2 \times \sqrt{2}}{\pi} = 0.900 \text{ for two phase}$$

$$\frac{3}{\pi} = 0.955 \text{ for three phase}$$

This factor is 0.900 for two phase and 0.955 for three phase for a large number of slots per phase per pole and is approximately correct for any number of slots per phase per pole above two. The factor in changing from two to three phase star then becomes

$$E_{3\text{-phase}} = \frac{1 \times \sqrt{3} \times \frac{2}{3} \times 0.955 \times E_{2\text{ phase}}}{0.900} = 1.225\, E_{2\text{ phase}}$$

T. P. K.

2053—Transformer Connections— We have three 60 000 volts, single phase transformers designed for a delta connected system. Would these transformers operate satisfactorily and safely at 100 000 volts if connected star? Can the ordinary service transformers primary 2200, secondary 220/110 be connected star to 3800 volts.

R. H. N. L. (B. C.)

For a delta connected system under normal balanced conditions, the voltage of each line above ground is approximately 58 percent of the delta voltage. When connected in star with grounded neutral, one end of the winding is 100 percent of the delta voltage above ground. In addition, the switching and other surges are higher for the star connected system. 2200 volt transformers are designed for use on either the delta or grounded star system, as this entails no material increase in cost. 60 000 volt transformers are designed for the particular service, as the difference in cost is an appreciable amount. The factor of safety for a delta connected 60 000 volt design used for star connection with neutral grounded would be reduced below safe limits.

G. A. B.

2054—Turbine-driven Generators— We have a 7.5 kw, four-pole, commutating pole, 250 volt, 3600 r. p. m. generator directly connected to a steam turbine. The armature has 111 bars and 28 coils; each coil containing four circuits wound as shown in Fig. (a). That is three circuits have two turns and one circuit has but a single turn. In general why is this coil made up with the single turn? The company representative said this was a peculiarity of generators designed for turbines.

G. W. S. (CALIF.)

The armature evidently has seven turns per slot and 28 slots, or a total of 196 turns on the armature. Since there are only 111 bars instead of 112, one slot has only three coils brought out, leaving either a one-turn coil or a two-turn coil dead. The total effective turns then must be 194 or 195, approximately. This number of turns could be made by using 33 slots, 99 bars, 2 turns per bar (total of 198 effective turns on the armature). The manufacturer has probably considered that the operation of the machine as shipped would be satisfactory, and has had some manufacturing reason for retaining the use of the 28 slot core or the 111 bar armature or both. Possible they

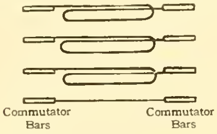


FIG. 2054 (a)

had been already developed and a 33 slot core and a 99 bar commutator would require expensive development. The deciding factor probably was expediency, not electrical performance. The odd winding is not a universal peculiarity of generators designed for turbines. In fact, few turbogenerators use such a wnding.

S. H

2055—Cross-connected Current Transformers—Explain two current transformers connected as shown in Fig. (a) (cross connected). Give formula for trip coil current in trip coil. What class of work is this used for? What is the advantage or disadvantage in having the two current transformers in parallel?

R. H. N. L. (B. C.)

This connection passes through the trip coil a current composed of two components, one from current transformer *A* and the other from current transformer *C*. For three-phase three-wire systems and balanced load, this resultant current through the coil is $\sqrt{3}$ times the current in either transformer secondary, at 30 degrees time phase from either of the components, and at unity power-factor it is in phase, or in phase opposition, to the voltage between lines *A* and *C*. Fig. (b) is a vector diagram for this condition in which E_{AB}, E_{BC}, and E_{CA} are the voltages between the lines, I_A, I_B and I_C are the line currents, and I_T the trip coil current, the formulae for the trip coil current, I_T is:—

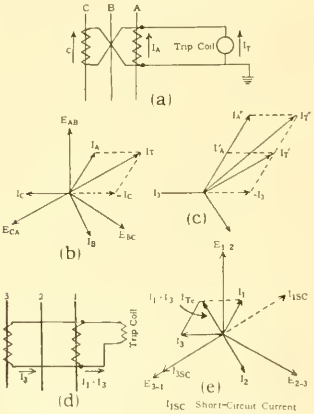
$$I_T = \sqrt{I_A^2 + I_C^2 + 2 I_A I_C \sin (30^\circ + \theta_A - \theta_C)}$$

In which θ_A and θ_C are the angles of lag of currents I_A and I_C respectively. When the angle of lag is the same for both currents sin $(30^\circ + \theta_A - \theta_C)$ reduces to sin 30° or ½ and the equation becomes:—

$$I_T = \sqrt{I_A^2 + I_C^2 + I_A I_C}$$

When I_A is equal to I_C the equation reduces to $I_T = \sqrt{3 I_A^2} = \sqrt{3} \times I_A$

This connection is used where it is desired to protect a three-phase three-wire line with only one available trip coil. Its disadvantage is that accurate single wire overload settings cannot be obtained because the trip coil current does not increase in direct proportion to the line current in the case of single phase overloads or short circuits. This may be better understood by reference to the vector diagram Fig. (c) in which I_A is shown twice the length of I_A but I_T is only about 50 percent greater than



FIGS. 2055 (*a*), (*b*), (*c*), (*d*) *and* (*e*)

I_T. This connection is used in voltage regulator work, also, when it is desired to obtain a current vector in phase with the voltage vector for use with an inductive drop compensator. The power in a three-phase three-wire circuit may be measured with a single-phase wattmeter by the use of this connection when the three-phase load is balanced:— See article by J. C. Group in The Electric Journal, April 1920 issue, Figs. 52, 53 and 54. The parallel connection between two current transformers is never used as no advantage is obtained and protection is sacrificed. Referring to Fig. (d) and (e) it will be seen that in case of short circuit between lines 1 and 3, current I_1 will then be equal to current I_3 (short circuit currents in this case are expressed as I_{1SC} and I_{3SC}), but 180 degrees out of phase with it. As the current in line 3 is then in phase with its voltage $E_{3\text{-}1}$, the current in the trip coil which is the resultant of I_{3SC} and I_{1SC} is now equal to zero and the trip coil will not operate.

M. R. & L. N. C.

2056—PHASING OUT SYNCHRONOUS MOTORS—If a synchronous motor is started from the alternating-current side and brings up a motor-generator set in one direction; and starting the motor-generator set from the direct-current side brings the set to speed in the same direction, does it denote that the phasing is correct?

G. H. (CALIF.)

If the direct-current machines were excited from the same bus, both when running as a motor and as a generator, the phasing is correct. If the machines, operating separately, start in different directions, simply reverse the direct-current generator field. Such a test can not be relied upon entirely, and it is good practice to check up the voltage, both in value and direction, each time a direct-current generator is paralleled with the lines. E. B. S.

2057—EFFECT OF INTERCHANGING LEADS—Please discuss the effect produced in a two-phase or three-phase generator when the leads to the field winding are reversed; would such a change necessitate "phasing-out" a generator before attempting to parallel it with others with which it had previously been operated in parallel. Discuss the same condition for the case of two generators premanently coupled mechanically.

C. S. (QUEBEC)

Consider two alternators operating in parallel. They are running at the same frequency (and also the same speed if the number of poles is the same) and their voltages are equal, both in phase and magnitude. If the field excitation on one machine is reversed, its voltage will be reversed or 180 degrees out of phase with the voltage of the other machine. This means that the rotor of one machine must shift an amount corresponding to 180 electrical degrees, in order to satisfy the conditions for parallel operation. If the machines had the same number of poles and they were set up with their shafts in line and end to end, it would simply mean that after the field was reversed on one machine, a pole which had formerly been a south pole, and lined up mechanically with a south pole on the other machine, would now be a north pole and the rotor would change its relative position so that this north pole would line up mechanically with a north pole on the other machine. In other words, the machines could still be operating in parallel after the field on one was reversed, although the relative mechanical position of the two rotors would be shifted by an amount corresponding to 180 electrical degrees. This shift might be any amount that is a multiple of a pole pitch. It would not be necessary to "phase-out" the machine. Reversing the field excitation does not change the relative phase position of the voltages in a polyphase machine. It merely reverses all of them and the relative position is unchanged. In the case of two generators rigidly coupled, the relative mechanical position of the two rotors cannot be shifted as discussed above. Therefore, the fields of the two generators must be excited so that their voltages will be in the same direction or in phase. Hence, with the excitation on the two machines such that the two are operating satisfactorily in parallel, they cannot be operated in parallel if the field excitation is reversed on one machine only. Reversing the excitation of both machines would, of course, make the relative condition same as before and they could be operated in parallel.

M. W. S.

2058—AMALGAMATION OF MERCURY IN AMPERE-HOUR METERS—We have trouble with the mercury in these meters getting thick, appearing to amalgamate with the copper disc. Is this an inherent fault with these meters or is it caused by too heavy currents being sent through the meter. The meters are on electric trucks and give only a few months service. In repairing these meters new mercury has been used, which I suppose is the only remedy. E. M. M. (CALIF.)

Mercury meters, when subjected to extremely high overloads, in addition to considerably increased temperatures, are affected somewhat by dross formation in the mercury chamber. This is especially true on electric trucks where the vibration is severe and the loads very high. About the only remedy in this case is to clean the mercury thoroughly or supply new mercury to the mercury chamber.

F. C. H.

2059—UNBALANCED LOAD FOR THREE-PHASE GENERATOR—Can a three-phase generator supply current to three single-phase lines, the load, varying from zero to full load on any phase? If not, why not? I understand a three-phase generator must be as nearly balanced as possible on all phases to operate properly. E. S. (ILL.)

The extent to which a three-phase generator can be used for supplying three separate single-phase lines is determined principally by the degree of voltage unbalanced which can be tolerated. With unequal loads and power-factors on the three phases, the voltage drop in each phase is different from that of the others, and the terminal voltages are therefore unequal. An attempt to raise the lowest of the three voltages, by increased excitation, will result in an equal percentage increase in all three voltages. A three-phase machine supplying one single-phase circuit is an extreme case of unbalanced load and the voltages of the three phases may be widely different. A generator that is subjected to unbalanced loads to any considerable extent or that is operated single-phase should be equipped with a damper winding. Without a damper winding, heating of the machine will take place, which may determine the limit of operation under these conditions. Distortion of the voltage wave form, particularly of the voltage from terminal to neutral, will also result. See "Comparative Capacities of Alternators for Polyphase and Single-Phase Currents" in Electric Engineering Papers by B. G. Lamme, or in the Journal for Aug. 1911, p. 672. Q. G.

2060—ELECTRIC FURNACES FOR REFINING STEEL—I would appreciate your best advice as to a method used for the final refining of molten steel with electric current after it is taken from the converter. Could this be done without the use of a complete electric furnace? What book would you recommend on electric furnaces and steel refinery by electricity?

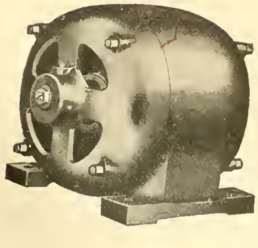
D. G. G. (WISCONSIN)

It is hardly feasible to attempt to refine converter steel without using a complete tilting-type electric furnace, for it is necessary to pour off one of more slags, which means that the furnace must be capable of being tilted, must be equipped with electrical apparatus for the proper supply of voltage and current, and should be equipped with automatic regulators. It is, however, true that a furnace merely for refining hot metal from the converter need not be so highly powered as a furnace which is expected to melt down cold scrap and then refine the metal. We recommend the latest edition of Stansfield's "Electric Furnaces". W. E. M.

2061—BRONZE DEPOSITED ON COLLECTOR RING BRUSHES—In the field circuits of our generators we have collector rings of bronze with 12 Speer Highgrade brushes ⅝ in. by 1/5 in. on each, The exciter rating is 480 amperes at full load. The negative rings only are subject to considerable wear and bronze is deposited in patches on the contact face of the brushes, although the surrounding carbon remains in contact with the ring. There is no sparking or excessive heating under the moderate load conditions. In the case of a direct-current generator, I understand, the presence of this "picked copper" reduced the brush contact resistance, permitting local current in the short-circuited coil thereby increasing the heating of the commutator and brushes. In the case of the collector ring is its presence detrimental? Are the brushes too abrasive? Does frequent dressing of the contact surface of the brushes increase the abrasive action? Can you suggest a remedy? The positive collector rings and brushes remain in perfect condition.

W. A. P (ONTARIO)

Your question indicates that the brushes are operated at very moderate densities, and presumably at moderate collector ring speeds, and it seems, therefore, that the trouble is probably caused by some local condition. We suggest, first of all, that the brushes and brush-rigging be inspected, to see if there is any appreciable vibration. Vibration prevents good contact between brush and ring, and will often start burning, which might deposit copper on the brushes. A similar effect might be produced if the brush pressure is low, or not uniform. Two pounds per square inch pressure, which in this case would mean practically two pounds per brush, has been found quite satisfactory. All brushes should be checked up to see that the pressure is correct. It has been found that oil or grease used as a collector ring lubricant, or the leakage of oil from a bearing to the ring, may cause the brushes to pick up copper. This might be investigated. It is suggested that the occasional reversal of generator excitation to alternate the polarity of the rings might reduce this trouble if it still persists. However, if the three causes mentioned above are eliminated, there seems to be no reason why satisfactory operation should not be insured. Frequent dressing of the brush contact surface with emery cloth need not increase the abrasive action if all the emery particles are carefully blown out, and the brush surface wiped. The condition of the positive collector ring suggests that the trouble is not due to the natural abrasiveness of the brush. E. B. S.



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EDITORIAL

ARTICLES

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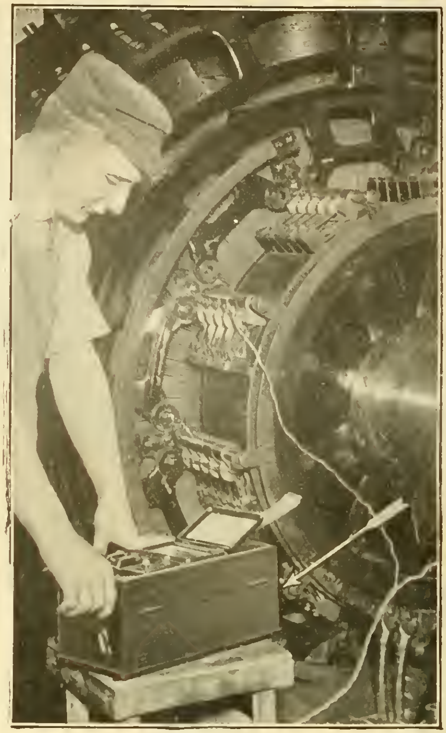

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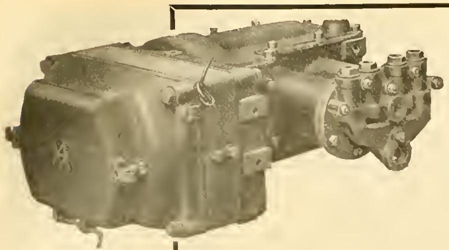

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THE ELECTRIC JOURNAL

VOL. XVIII DECEMBER, 1921 NO. 12

The Development of Our Water Powers

It is generally appreciated that the successful development of our water powers merits a definite place in our program for economic welfare. Hydroelectric development represents a definite conservation of our gradually diminishing fuel supply, thereby making it available for the future or releasing it for other necessary purposes.

What is not so generally known or appreciated, however, is the difficult problem of the hydraulic engineer in providing suitable apparatus to handle these natural forces, and the factors to be taken into consideration in their application. The electrical engineer has provided for the transmission of electrical energy over long distances, permitting hydroelectric developments that could not be undertaken before the days of the high-voltage transmission. Our water powers are, therefore, a potential source of energy, waiting to be utilized, but requiring careful engineering analysis to a greater degree than probably any other undertaking.

A total of approximately 10 000 000 horse-power, in hydro-electric power is actually developed in the United States today, and our available undeveloped water powers are estimated at approximately 55 000 000 horse-power. While possibly a large portion of this could not be undertaken economically at the present time, applications totaling approximately 15 000 000 horse-power, have been filed with the Federal Water Power Commission since the recent passage of the Water Power Bill; a measure long needed and which has added a real stimulus to this important phase of our economic development by insuring an equitable administrative control of our natural water power resources.

While the use of water power is by no means new, the real development of the water turbine practically parallels that of the alternating-current generator. The development has been two fold, one of increasing unit capacity and speed and one of higher efficiencies. Twenty-five years ago units of 5000 hp, were the largest to be found. Even as recent as ten years ago 20 000 hp was the maximum, yet today units as large as 50 000 hp, have been built and are in successful operation, and definite plans have been made for the installation of units up to 75 000 hp. Efficiencies have increased from 75 and 80 percent to as high as 93 percent or more. This performance, together with improvements in the present-day electric generator have made possible overall efficiencies as high as 90 percent for the combined hydroelectric unit. But progress has not been confined to the larger and more spectacular units, as more efficient and higher speed wheels are now available for small powers, at heads as low as eight feet, and are being utilized by the hundreds. Formerly, such plants were not feasible on account of the prohibitive cost of development, due to non-suitable apparatus and its inefficient operation.

Increased efficiency of hydraulic turbines is of especial importance in those installations where the quantity of water available is limited during certain seasons of the year, either by lack of storage facilities, as is the case in many of our Western and Southern developments, or by legal restrictions, as at Niagara Falls. Where a large amount of money has been invested in storage dams and in long distance transmissions, it is important that the maximum return on this investment be secured. In such cases an increased turbine efficiency of ten percent means a corresponding increase in the power that can be generated with the same amount of water, and this increased percentage may mean the difference between the financial success or failure of the installation.

The article on "Hydraulic Reaction Turbines" in this issue of the JOURNAL is of particular interest in bringing one to a realization of the many factors to be considered in the successful design and application of the modern water wheel. Efficiency, simplicity, durability and continuity of service are all of the greatest importance. These features involve not only the turbine design but all the water passages from the forbay to the tail race, and the auxiliary equipment as well. Fundamentally the first cost of the hydroelectric station generally exceeds that of the steam station. This has led to the use of the maximum feasible capacities and speeds in the individual units, in order to take advantage of the accompanying reduction in cost per unit output of both the water wheel and the generating equipment. The range of application of the reaction turbine has also been extended, thereby increasing its general adaptability to meet the varying condition encountered.

It is gratifying to note the manner in which these various problems in design and application are being met and the assurance it gives for our future progress.

A. L. SCHIEBER

Hydraulic Reaction Turbines

D. J. McCORMACK
Hydraulic Engineer,
Wellman-Seaver-Morgan Co.

GREATER interest is being shown in water power development at present than at any time in the past. This is due largely to the high price of fuel transportation and labor, the realization of the limited extent of our fuel reserves, and the great strides made of late years in increasing the efficiency of the development and transmission of water power. It is therefore evident that the method of applying modern hydraulic reaction turbines in the development of water powers, and an outline of the advances in hydraulic turbine practice will be of great engineering interest.

CLASSIFICATION OF REACTION TURBINES

Single vertical turbines, according to head

1—From 8 to 30 ft. head ....open flume.

FIG. 1—FIRST LARGE VERTICAL TURBINE BUILT

A 10 000 hp, 32 ft. head, 57.7 r. p. m. turbine installed at the Keokuk Plant of the Mississippi River Power Company.

2—From 17 to 95 ft. head..........concrete spiral casing.
3—From 40 to 200 ft. head ....steel plate spiral casing.
4—From 60 to 450 ft. head ....cast iron spiral casing.
5—From 300 to 800 ft. head ....cast steel spiral casing.

Horizontal turbines

1—Single, twin, triplex, quadruplex, and sextuplex open flume, 8 to 40 ft., head inside gate mechanism.

2—Twin and quadruplex, end inlet, 15 to 140 ft. head, steel plate cylindrical casing being an extension of the penstock, inside gate mechanism.

3—Twin side or top inlet, steel plate cylindrical casing, 15 to 140 ft. head, inside or outside gate mechanism.

4—Single cast iron or cast steel spiral casing, 60 to 600 ft. head, quarter turn discharge—outside gate mechanism.

5—Twin cast iron or cast steel spiral casing, center discharge, 60 to 200 ft. head, outside gate mechanism.

6—Double discharge, 200 to 450 ft. head, one cast iron or cast steel spiral casing, two quarter turns, outside gate mechanism.

7—Single cast iron or steel plate conical casing, 40 to 140 ft. head, inside gate mechanism—for small exciter turbines—less expensive than spiral casing.

VERTICAL TURBINES

In the above classification, multiple-runner vertical turbines have been omitted. This type has been superseded by large, single-runner vertical machines having high specific speed runners. They had the disadvantages of a very inefficient draft tube and flume arrangement, an exceedingly deep flume, all turbine parts submerged in the water, causing much higher maintenance charges, and generally insufficient water seals over the top of runner to prevent air from being drawn into the wheel. Open flume turbines allow a very inexpensive construction of turbine and flume, which is

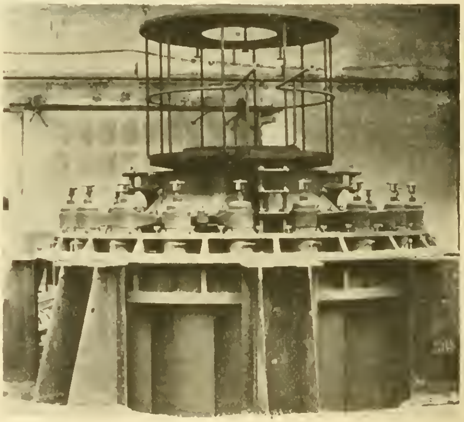

FIG. 2—THE LARGEST SIZE TURBINE EVER BUILT

A 10 800 hp, 30 ft. head, 54.3 r. p. m. turbine for the Cedars plant of the Cedars Rapids Mfg. & Power Co., Montreal, Canada.

imperative with exceptionally low heads in order to keep down the fixed charges.

At present costs, for heads over 25 ft. and units over 1500 hp, the additional cost of a concrete spiral casing and outside type of gate mechanism and bearing for a turbine is justified by the increase in efficiency, the decrease in repairs and renewals of turbine parts, and the greater reliability and continuity of service. The maximum head for a concrete spiral casing is about 95 ft. and there is an installation of 30 000 hp units under that head in course of construction now. For heads over 60 ft. there is a decided tendency to use circular instead of rectangular sections for concrete spiral casings to reduce the amount of reinforcing bars.

Where the water is led through steel penstocks from a diversion dam to the power house, it is customary to use steel-plate spiral casings connected directly onto the steel penstocks for heads as low as 50 ft. However, for such a head, if the penstock is exceptionally long an inexpensive construction is to form a concrete surge tank along the wall of the power house and take concrete spiral casings from this. A wood stave pipe can then be used instead of steel.

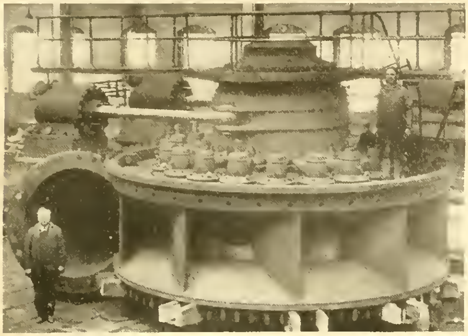

FIG. 3—LARGEST CAPACITY TURBINE EVER BUILT
A 61 000 hp, 305 ft. head, 187.5 r. p. m. turbine for the Queenston Plant of the Hydro-Electric Power Commission of Ontario.

Single vertical turbines are recommended in this country for all new hydro-electric installations. Horizontal turbines are still being used on foreign developments, but of late there has been a noticeable conversion to vertical units in the foreign developments. For replacing old horizontal wheels or in adding units to old horizontal plants, horizontal wheels are still being built, but even under these conditions many vertical turbines are being installed. Horizontal wheels are also

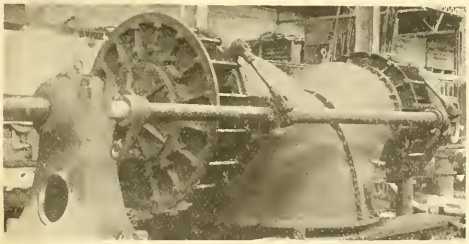

FIG. 4—TWIN HORIZONTAL OPEN FLUME TURBINE
A 3 200 hp, 64 ft. head, 257 r. p. m. turbine installed at the plant of the New England Power Company, Shelburne Falls, Mass.

used now for construction jobs or other temporary purposes when efficiency is not important.

Before the advent of the electrical generator, vertical wheels were used as often as the horizontal type, for driving sawmills, grist mills, and factories through line shafting and gearing. When coupled direct to generators, horizontal wheels with single or multiple runners were used extensively, on account of the higher speed possible with two or more small runners on a shaft. This of course greatly reduced the cost of the generator.

It used to be considered that horizontal wheels running at 210 to 240 r.p.m. were the best drive for pulp grinders. This practice is being supplanted by the use of vertical hydro-electric units and driving the grinders by synchronous motors. A greater production and better grade of pulp is obtained on account of the uniform speed. Such a system has the advantages of a high-power factor and a large amount of flywheel ef-

FIG. 5—SEXTUPLEX HORIZONTAL OPEN FLUME TURBINE
A 2770 hp, 17 ft. head, 100 r. p. m. unit installed at the plant of the Southern Wisconsin Power Co., Kilbourn, Wisc.

fect to take care of the other industrial and lighting load.

The greatest advantage of single vertical turbines over horizontal is the increased efficiency. From three to seven percent higher efficiencies are being obtained. This can be credited in large degree to the absence of the bends, such as occur in the quarter turn or double discharge casing of a horizontal turbine at the discharge of the runner, where the velocity is very high. For large capacity units under a low head, where two or more draft tubes would be necessary for a horizontal unit with several runners, there is a further loss in the draft tubes. Also these draft tubes are so long in the horizontal direction that surges, and in some cases part-

FIG. 6—END INLET, CYLINDRICAL CASING TURBINE
A 5 600 hp, 72 ft. head, 240 r. p. m. unit installed at the Healy Falls Plant of the Hydro-Electric Power Commission of Ontario.

ing of the water column, are caused and the turbine regulation is seriously affected. The water approaches a vertical wheel with a better flow, devoid of sharp turns under high velocity, such as is evident with most horizontal settings. Where the height of the tail water fluctuates considerably, the vertical arrangement allows the generator to be set well above the wheel and tail

water, and thus precludes any possibility of flooding the generator floor. The design is simplified, there are fewer parts and generally only one turbine bearing is required. Where an outside gate mechanism and outside bearing is used the cost of renewals, repairs and consequent interruptions in service are greatly reduced. Due to the greatly increased speeds of low-head runners

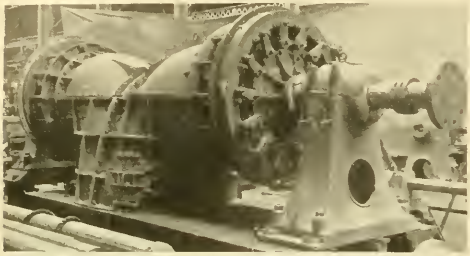

FIG. 7—A TWIN TURBINE WITH OUTSIDE GATE MECHANISM FOR TOP INLET CASING

A 4 800 hp, 100 ft. head, 360 r. p. m. unit with two bronze runners installed at the plant of the Olympic Power Co. at Port Angeles, Wash.

developed lately, and the fact that the electrical companies now have developed a full line of vertical generators, the first cost in most cases is comparable with horizontal machines.

A great element in the success of large vertical units has been the development of the thrust bearing to a high state of perfection. They have proved perfectly reliable in service. The allowable bearing pressures range from 250 to 400 lbs. per sq. in., depending on the speed. The thrust bearing is now considered a part of the generator and is furnished by the generator manu-

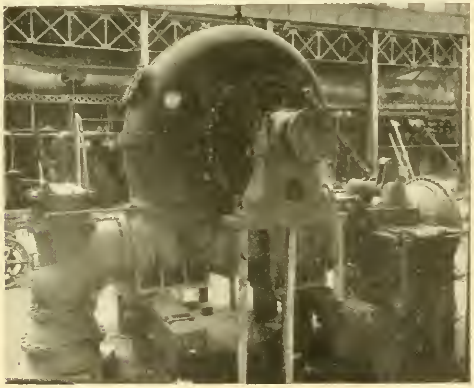

FIG. 8—A SINGLE HORIZONTAL SPIRAL CASING TURBINE

A 6 400 hp, 320 ft. head, 514 r. p. m. turbine installed at Mt. Hood Plant, Portland Railway, Light & Power Company.

facturer, being mounted above the upper generator guide bearing.

HORIZONTAL TURBINES

With open-flume horizontal turbines, the runners should be submerged enough below head water to prevent air being drawn into the wheel. The height of seal will vary with the size of wheel. In cases of extremely low head it has been necessary to have a raft above the wheels in order to prevent vortices forming.

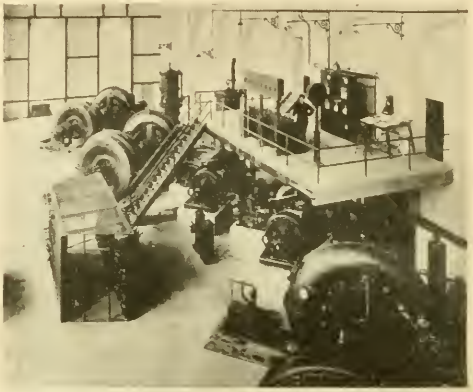

FIG. 9—AN INSTALLATION OF HORIZONTAL TURBINES

Showing three 6 400 hp, 320 ft. head, 514 r. p. m. main turbines and two turbine driven exciter units at the plant of the Portland Railway Light & Power Co., Portland, Oregon.

If there are two or more concrete draft tubes to a unit with multiple runners, the horizontal length should be reduced as much as possible. Otherwise the inertia of the water in the long draft tube becomes so great that upon a sudden closure of the gates the water column will part, especially with a high draft head, and come back with a bang like the report of a cannon, causing serious damage to the turbine. It is very hard to regulate a turbine under such conditions.

End inlet, cylindrical-casing turbines, Fig. 7, are a less expensive construction and provide a better dis-

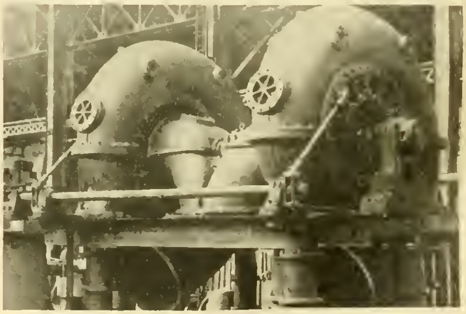

FIG. 10—TWIN SPIRAL CASING HORIZONTAL TURBINE

A 2 300 hp, 56 ft. head, 300 r. p. m. unit at the Big Chute Plant of the Hydro-Electric Power Commission of Ontario.

tribution of water to the runners than a side or top inlet, but are not adapted to the use of the outside type of gate mechanism. For heads of 90 ft. or over, the side or top inlet casing with outside gate mechanism as shown in Fig. 8, is used, mainly due to mechanical reasons, i.e. to withstand the unbalanced forces on the bulkheads

and to have all possible parts outside of the water passages.

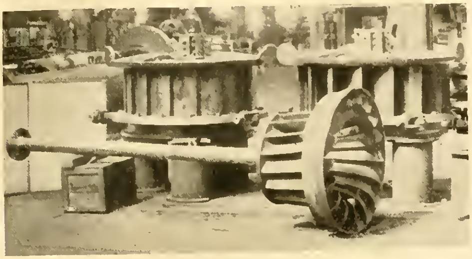

FIG. 11—A SINGLE VERTICAL OPEN FLUME TURBINE
A 500 hp, 25 ft. head, 200 r. p. m. unit built for Oswego Falls Pulp & Paper Co., Fulton, New York.

High-head, single, horizontal turbines in cast-iron or cast-steel spiral casings, Fig. 9, were for a time not favored on account of the unbalanced end thrust on the runner. This was overcome by proper design of the balancing chambers on the two sides of the runner, balancing pistons or pipe connections around the casing from the crown plate to the draft tube, and cored holes through the runner hub.

Double discharge turbines allow higher rotative speeds than single on account of the smaller diameter of the runner. They are also well balanced for end thrust. However, they are limited where the band of the runner becomes so large in respect to the entrance diameter of the runner that it is impossible to work on the gate mechanism. This type of turbine is generally set with the shaft lengthwise of the power house in order that one draft tube will not have to pass by the other, and also to eliminate bends in the feeder pipe. This of course requires a longer power house.

A single spiral casing for a double discharge turbine often becomes too big for large-capacity, medium-head turbines. It is then necessary to use two spiral casings with a central double discharge casing, as shown in Fig. 11. The units are generally placed with the shaft crosswise of the power house to save space, and a Y-pipe distributes the water to the two casings. As the double discharge casing is less efficient than two quarter turns, one or two installations have been made with a single discharge turbine on each end of the generator.

LIMITS OF HEAD FOR REACTION TURBINE

The minimum head for a commercially successful hydroelectric plant, with present costs of materials, lies between 8 and 12 feet depending on the length of dam and the other considerations entering into its construction. It is then possible only by using the highest speed runners available with open flume setting of turbine, as shown in Fig. 12. A high load factor, high power-factor, fairly uniform flow, low cost dam, controlling works and power house are the requisites of a successful development.

At the other extreme, reaction turbines are limited as to maximum head in most cases by the speed of the generator. There is a sudden and decided increase in the cost of the generators when the speed exceeds the limit for standard construction and it becomes necessary to use the steam turbine type of generator with nickel steel rotor to withstand the high centrifugal forces.

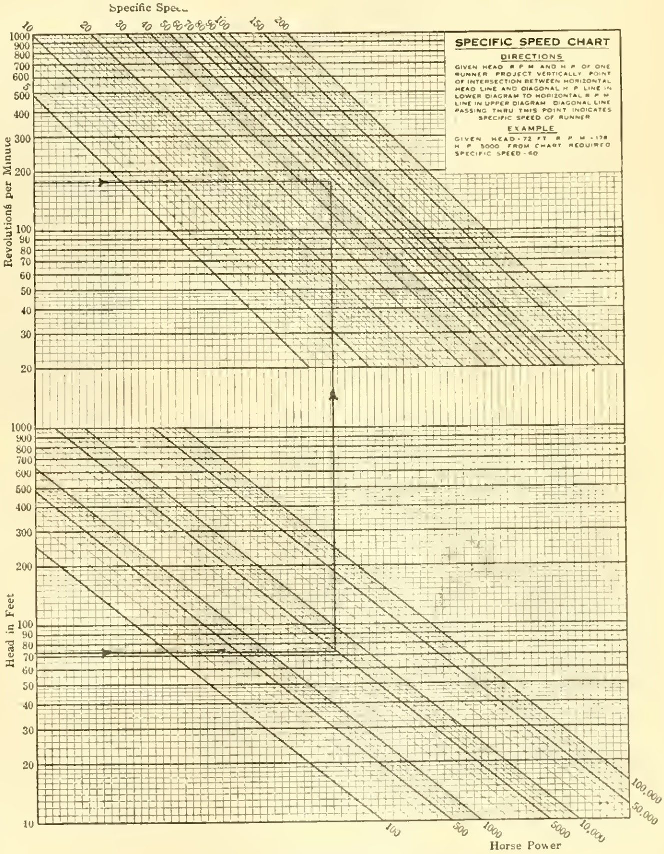

FIG. 12—SPECIFIC SPEED CHART

For example—a 6000 kv-a generator at 1200 r.p.m. will cost nearly twice as much as a 600 r.p.m. machine of the same capacity. For these exceptionally high heads, reaction turbines having specific speeds below 16 are not

as suitable as those having specific speeds of around 20 or over. With the lower specific speeds, the runners and other parts offer too great a wetted perimeter, which increases the frictional losses. There is also less over-

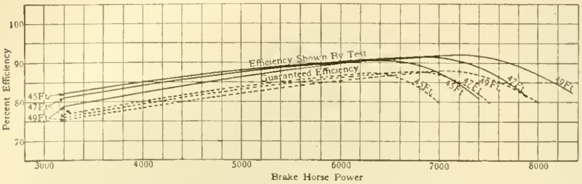

FIG. 13—COMPARATIVE GUARANTEED AND FIELD TEST PERFORMANCE CURVES

Taken at 45, 47 and 49 ft. head on a 7 500 hp, 100 r. p. m. turbine at the Junction Development of the Consumer's Power Co., Wellston, Mich.

pressure at the entrance to the runner and a greater curvature in the vanes which increases the tendency to corrode.

Further, a limit is reached where the velocity head at the top of the draft tube $\left(\frac{V^2}{2g}\right)$ approaches the head due to barometric pressure. The allowable draft head is then correspondingly reduced. In one case where 1000 ft. head was considered, the velocity at the top of the draft tube of 50 ft. per sec. would require the runner to be submerged below tail water in order to maintain the water column in the draft tube, and to take advantage of the full head. In several installations where the velocity head at the top of the draft tube added to the draft head approaches the head due to barometric pressure, a crackling noise is set up in the draft tube. Upon sudden load changes of any magnitude, the water column parts and comes back with such tremendous force that it shakes the entire power house. This condition is, of course, destructive to the turbine parts, par-

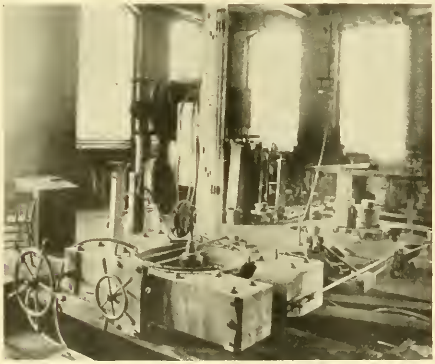

FIG. 14—HOLYOKE TESTING FLUME

ticularly the runners, quarter turns and metal draft tubes. It also increases the pitting action and may be relieved to a great extent by admitting air into the draft tube.

The highest head yet attempted for a reaction turbine is 800 ft. This may be exceeded in the future with very large capacity units. The difference in efficiency between 93 percent for reaction turbines and 85 percent for impulse turbines is a very attractive incentive for pioneering in the high-head field for reaction turbines.

TURBINE CHARACTERISTICS

"Specific Speed" is a term used to designate the type of a turbine runner or wheel. It is the speed at which the wheel would run if it were reduced in size, without changing the design, so as to develop one horse-power under one foot head.

$$\text{Or, } \textit{Specific Speed, } N_s = \frac{R.p.m. \times \sqrt{Hp.}}{H \times \sqrt[4]{H}}$$

A convenient graphical method of deducing the specific speed without using this formula is afforded by Fig. 12.

Specific speed is a complete measure of the possible performance of a runner under any head, both as to power and speed. It is not a measure of its efficiency

FIG. 15—TURBINE READY TO TEST IN HOLYOKE WATER POWER COMPANY'S TESTING FLUME

but, aside from that consideration, it is an absolute type characteristic and, given the specific speed of a runner, it is possible to decide at once whether it is suitable for a given set of conditions.

European practice is to use exceedingly high specific speeds, even for medium and high heads, in order to reduce the cost of the generator, regardless of other considerations. It has been the experience in this country that if too high specific speeds are used, particularly for medium and high heads, the runners are liable to show corrosion or pitting, due mostly to the excessively high velocities through the runner. A limiting value of specific speed for any given head as determined by experience is: $N_s = \frac{5050}{H + 32} + 19$.

For high heads a low specific speed runner is used. This type of runner gives a flat efficiency curve over a wide range of power and also over a wide range of speed or head. High part gate, and full gate efficiencies are obtained, and the maximum efficiency occurs at about 75

to 85 percent of full load. A low head runner of high specific speed gives a more peaked curve over the power range and for a variation of speed or head. The part gate efficiencies are lower, and the maximum efficiency occurs at 90 to 93 percent of full load.

may show a difference of three to four percent in efficiency unless the speed is set to suit the characteristics of the wheel. This is particularly important for a variable head plant.

Tests made on 25 to 30 inch model runners at the

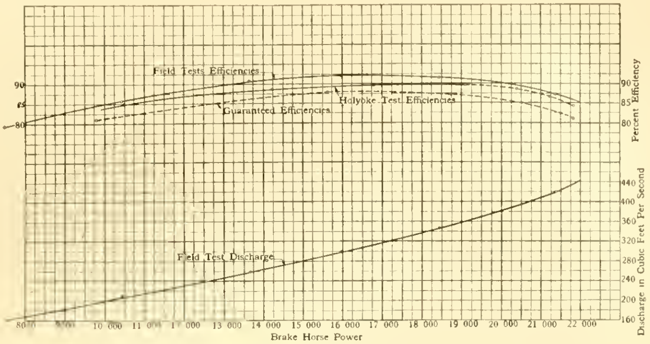

FIG. 16—COMPARATIVE GUARANTEED, HOLYOKE AND FIELD TEST, PERFORMANCE CURVES
For 22 000 hp, 515 ft. head, 428 r. p. m. single vertical turbines.

When the turbine is used to drive a generator it has to run at a constant speed, but if the head varies from normal, the efficiencies will be affected the same as if the head were maintained constant and the speed varied, as shown in Fig. 13.

On large units, it is sometimes desirable to block the gate stroke at the gate opening corresponding to maximum efficiency, and not allow the turbine to pull a greater load. The governor can regulate the gates up to this opening and the units are operated at this point of maximum efficiency as much as possible. This is called "running against the block" and is very good practice where steam auxiliaries or low head regulating plants are connected to the system and can take the fluctuation of loads.

The number of units to be installed in a plant is dependent to a great extent upon the variation in stream flow throughout the year and upon the part gate efficiencies of the turbines. In order to maintain a high average operating efficiency of the plant with a wide variation of loads, it is necessary to use a larger number of units for a low head plant than for a high head plant of the same capacity. A high head development generally has a more uniform flow and the part gate efficiencies of the turbines are higher.

The speed of the unit should be left to the turbine manufacturers. A generator can be built for any synchronous speed within a wide range and give within one percent of the same efficiency for the same capacity. However, a turbine is much more sensitive to speed and

Holyoke testing flume form the only direct comparative results of the various manufacturer's designs of runners, as this is the only official testing flume in the United States. All tests are made there under the same conditions of apparatus, methods and men. The results of the Holyoke tests are applicable to the prediction of the performance of a larger turbine under a different head.

The speed will vary inversely as the diameter of the runners and directly as the square root of the head. The horse-power will vary as the diameters squared and as the three-halves power of the head. The

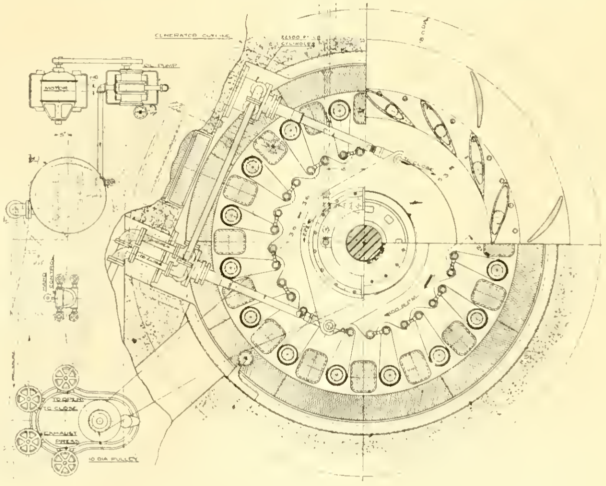

FIG. 17—PLAN VIEW OF A 4250 HP., 32 FT. HEAD, 100 R. P. M. VERTICAL TURBINE

quantity of water flowing will vary as the diameter squared and as the square root of the head.

(To be continued)

Circle Diagrams for Transmission Systems

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NO method for the complete graphical solution of power transmission problems has been developed up to the present time, which in itself covers all sets of conditions with any degree of accuracy. The possible combinations of networks for this type of problem are quite varied, and it has been shown by the authors* that any of these combinations can be replaced by an equivalent network represented by a single set of general circuit constants, which can be applied in the usual manner. This article is, therefore, limited to the development of a graphical method for the complete solution of transmission problems in their many and varied forms.

The primary object of an approximate graphical solution is not one of accuracy, although this should be within a few percent of that obtained by an exact method of calculation but one that gives, in as simple and general way as possible, a maximum set of solutions with a minimum of calculation. When such a diagram has been finished, the most desirable conditions of operation can be readily selected, and the rigid mathematical solution may be applied to the particular case with any further degree of accuracy that may be desired. Usually this is unnecessary for the majority of problems, as a good graphical method is limited in accuracy only in the drawing and reading of the scalar quantities.

DWIGHT CIRCLE DIAGRAM

The circle diagram, as developed by Mr. H. B. Dwight* and as quite generally used, gives the conditions of load necessary at the receiver end of the line to obtain a certain voltage regulation. In a recent article, it was shown by the writers that the general circuit constants can be developed so as to include all portions of a transmission system from the low-tension bus of the generator to that of the receiver. In any case, these constants reduce to the familiar form of the hyperbolic or convergent series method:

$$E_s = A_o E_r + B_o I_r \qquad (1)$$
$$I_s = C_o E_r + D_o I_r \qquad (2)$$
$$E_r = D_o E_s - B_o I_s \qquad (3)$$
$$I_r = -C_o E_s + A_o I_s \qquad (4)$$

Where, A_o is equal to D_o for the symmetrical line, i.e., the case of the transmission line alone, or where similar supply and receiver transformers are included. The constants A_o, B_o, C_o and D_o have particular values, dependent upon the transmission line conductors and their spacing, equivalent transformer impedances, and the operating conditions assumed. Table III* is very useful in determining these constants for various conditions.

The development of the circle diagram from equation (1) shows that for given generator and receiver voltages there are particular circles whose ordinates represent the total reactive power and whose abscissae represent the total real power at the receiver, the particular values of which are fixed according to the voltages assumed. Similarly, from equation (3), it may be shown that the generator conditions are determined by a circle based upon the assumed voltages. The constants of these particular circles may be expressed conventionally as follows:

$$A_R = \frac{3\, l\, E_r^2}{1000} \;\ldots\ldots (5) \qquad A_s = \frac{3\, l'\, E_s^2}{1000} \;\ldots\ldots (8)$$
$$B_R = \frac{3\, m E_r^2}{1000} \;\ldots\ldots (6) \qquad B_s = \frac{3\, m'\, E_s^2}{1000} \;\ldots\ldots (9)$$
$$C_R = \frac{3\, n E_r E_s}{1000} \;\ldots\ldots (7) \qquad C_s = \frac{3\, n E_s E_r}{1000} \;\ldots\ldots (10)$$

where the nomenclature is fully explained in the appendix.

This completes the diagram up to the point where the generator and receiver conditions can be determined for any given voltages. That is, for any given power load, Kv-a_R and Kv-a_S can be determined from the ordinates at the intersection of the power abscissa corresponding to that load and the receiver and supply circles respectively, as shown in Fig. 1*. Any point not on the circle represents a different voltage condition than that assumed. Hence when a vector representing a given kv-a load at a given power-factor, such as that shown in Fig. 1, does not end on the receiver circle, a synchronous condenser is required in order to maintain the assumed voltage conditions. The condenser capacity required is represented by the vertical line dropped from the load vector to the receiver circle. Thus in Fig. 1, the shaded area represents the synchronous condenser capacity required to maintain the receiver voltage constant and equal to a constant supply voltage at the assumed values, at all loads from zero to full load, as identified by lag and lead. The vector shown for Kv-a_S neglects the transmission losses and represents 100 percent efficiency.

It will be seen from the diagram that all phase relations can be very easily determined directly for all loads, and by plotting other circles for different voltage conditions, for practically any regulation. Since l, m, l', m', and n depend entirely upon the general cir-

*"Transmission Lines and Transformers", in the JOURNAL for Aug. 1921, p. 356.

*See article on "The Calculation of Constant Voltage Transmission Lines" by H. B. Dwight in the JOURNAL for Sept. 1914, p. 487.

*In the JOURNAL for Aug. 1921, p. 358.

*Some prefer to plot the circle diagrams so that positive Q refers to leading Kv-a. However, when inductive reactance is taken as $+ j\, x$ and capacitance as $+ j\, B$, this is not mathematically consistent. For this reason, minus Q refers to leading Kv-a in this article, and in order to plot the diagram the other way the formulas or diagrams given must be reversed in sign as far as Q is concerned.

cuit constants of the system, which are constant for a given network and voltage class, the circle diagram constants can be calculated very simply for a variety of voltage combinations at the supply and receiver ends. This is quite useful in representing the conditions obtained by utilizing compensated voltage regulation at the generator, a falling receiver voltage characteristic, or constant voltage transmission at either end or at both ends by the use of synchronous condensers at the receiver.

and (7). For a given load and power-factor at the receiver, the generator conditions at 100 percent efficiency will be given by the intersection of a perpendicular to the P axis with the supply circle having the same regulation as determined by the receiver circle. The receiver voltage for any load at any power-factor, in percent of E_R can be readily determined by

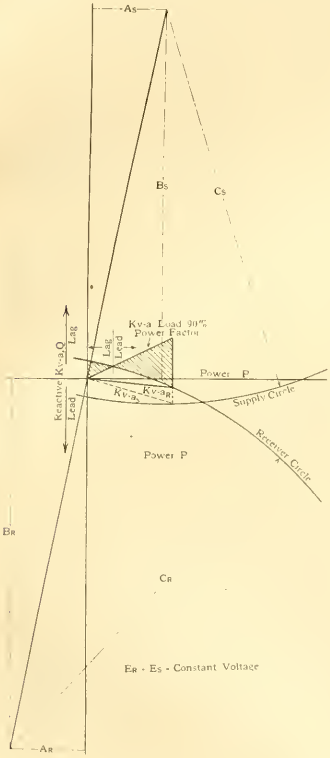

FIG. 1—METHOD OF DETERMINING THE SYNCHRONOUS CONDENSER CAPACITY

To obtain the voltage regulation desired for any load at a given power-factor.

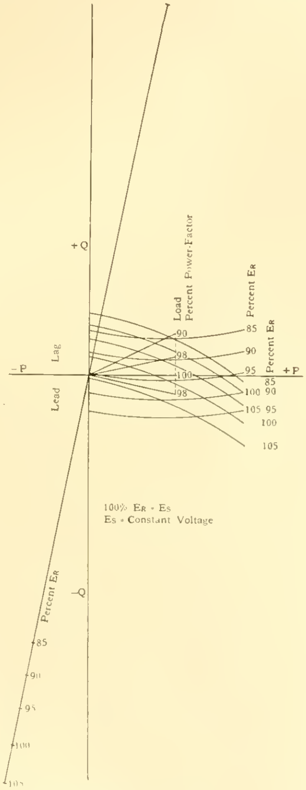

FIG. 2—VARIATION IN RECEIVER VOLTAGE

For constant supply voltage with constant load at variable power-factors.

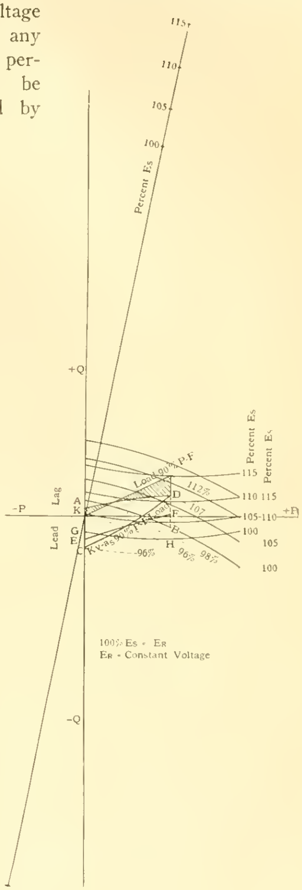

FIG. 3—THE EFFECTS OF VOLTAGE COMPENSATION

At the supply end for a given load and power-factor.

The diagram shown in Fig. 2 is representative of the conditions obtained when the generator voltage is held constant and the receiver voltage is free or unregulated and takes a value determined by the constants of the circuit and the load conditions on the receiver. With constant generator voltage, the center of the supply circle is constant, as located by equations (8) and (9) but the radius varies with the receiver voltage (10). The center and radius of the receiver circles vary in accordance with equations (5), (6)

interpolation on such a chart. This, gives, perhaps, one of the plainest graphical representations of the effects of variation in load and power-factor upon the regulation, and the load and power-factor conditions obtained at the generator.

Conversely to the above, the diagram shown in Fig. 3 is representative of the conditions obtained when the receiver voltage is considered constant and the generator voltage variable, a condition such as would be obtainable by the use of a compensated voltage regu-

lator. It is shown in the diagram, with the load assumed, that 16.5 percent voltage compensation, based upon the minimum generator voltage, is the maximum necessary to maintain constant receiver voltage without using a synchronous condenser. That is, at no load, the receiver circle must be drawn through the zero load point, corresponding to a voltage of 96 percent E_S, as shown by the dotted line, and at full load the receiver circle must be drawn through the full

TABLE I—EFFECT OF VOLTAGE COMPENSATION

Percent Generator Voltage		Percent Compensation	Percent Maximum Condenser Capacity	
No Load	Full Load		Lag	Lead
96	112	16.5	0	0
98	107	9	15	40
100	100	0	30	100

load point, corresponding to 112 percent E_S. In practice it is not necessary to draw the circles which are shown dotted, as these points can readily be interpolated.

With only nine percent voltage compensation, such as between 98 and 107 percent voltage, the synchronous condenser required will be as designated by the cross-hatched area. Intermediate points on the curve *KD* are obtained by assuming straight line compensation as illustrated in Fig. 4 for five percent. Then the point on this curve for any load is at the intersection of the ordinate for that load with the receiver circle corresponding to the voltage on the compensation curve at that load. These conditions show that only 60 percent of the load could be carried with nine percent compensation without a synchronous condenser, as represented by the intersection of the 105 percent (96 + 9) receiver circle with the load line. In order to carry this same load with zero voltage compensation at the generator, it would be necessary to increase the condenser capacity to 2.5 times that with nine percent compensation, as represented by the dotted line at full load, and throughout the range of load as bounded by the section of the 100 percent circle *AB* and the 90 percent power-factor load line. A summary of the diagram for the same loads is shown in Table I, in which the maximum condenser capacity required with zero compensation is assumed as 100 percent.

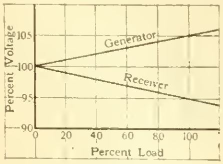

FIG. 4—STRAIGHT LINE VOLTAGE REGULATION

At both supply and receiver ends.

The conditions at the supply end in Fig. 3 are represented by the line *CD* for a 90 percent power-factor load with 16.5 percent compensation and no synchronous condenser, any point on this curve being at the intersection of the load ordinate with the supply circle for the voltage corresponding to that load. With nine percent compensation and 40 percent synchronous condenser, the line *EF* represents the supply kv-a for different loads. For zero compensation and with receiver conditions defined by line *AB*, the corresponding supply conditions are defined by line *GH*.

By combining the two conditions shown in Fig. 2 and Fig. 3, that is, using compensated voltage regulation at the generator and allowing the receiver voltage to fall off according to the curves in Fig. 4, conditions will be obtained as shown in Fig. 5. Here it is again shown that the synchronous condenser capacity has been materially reduced over that which would be required with equal and constant supply and receiver voltages. In fact in this particular case, the conditions are very similar to the conditions in Fig. 3, using nine percent compensation with 40 percent synchronous condenser.

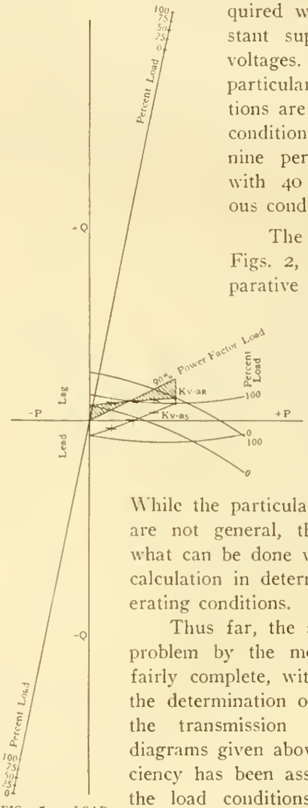

FIG. 5— LOAD CONDITIONS

Obtained at the supply end with voltage conditions at both ends as shown in Fig. 4.

The three diagrams Figs. 2, 3 and 5, are comparative as they were taken from an actual problem of a given load and given transmission system and the 100 percent circles are the same in each. While the particular percentages given are not general, they serve to show what can be done with this method of calculation in determining the best operating conditions.

Thus far, the solution of a given problem by the methods indicated is fairly complete, with the exception of the determination of the line loss and the transmission efficiency. In the diagrams given above, 100 percent efficiency has been assumed to determine the load conditions at the generator with a given load at the receiver, but there is an exact method which may be used to correct for this.

LOSS EQUATIONS

The line loss is usually determined from either the RI^2 loss or the difference of the generator and receiver loads. However, the former method is in error, due to the effects of the line charging current upon the load current. The latter method is usually approximate as far as calculations go, unless these are carried out on a calculating machine, as this method involves the small difference of two large quantities. It is possible to express the generator and receiver power

in general terms and show that the difference of the power components gives the total line or transmission loss. This may be expressed as:

$$Total\ loss = tP_R + uE_R^2 + 3vI_r^2 + wQ_R \ldots\ldots (11)$$

where t, u, v and w are constants, dependent upon the general circuit constants, as explained in the appendix.

The terms in the above expression may be identified in the following manner: The second term represents the no-load loss of the system. The third term gives the equivalent RI^2 loss due to the load current alone. Since the charging current and load current flow through the same conductor, the total loss involves more than the RI^2 loss of the individual currents as given by the second and third terms. This additional loss will vary with the relative phase relations of the two currents and is provided for by the first and fourth terms.

The total loss that is chargeable to transmission is made up of three parts, namely, transformer, transmission line, and synchronous condenser. If the general circuit constants have been applied, all or a part of the transformer losses and the transmission line losses will be given by equation (11) and to this can be added the other losses for determining the

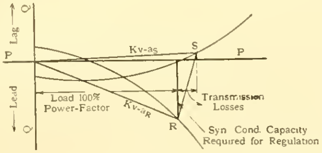

FIG. 6—METHOD OF DETERMINING SUPPLY LOAD CONDITIONS

With given receiver conditions, including transmission losses.

transmission efficiency. However, this may not be the most convenient or easiest way to make the calculations, as the segregated losses of the transformers may not be at hand if they have not all been included in the general circuit constants. If this is the case, the transmission line loss may be calculated alone for the different loads and the efficiency curves of the transformers and condensers may be used to plot the resultant efficiency curve.

LOSS ON THE CIRCLE DIAGRAM

Having provided a means for accurately determining the transmission losses, these may be added to the receiver load for determining the conditions of load at the supply end, as shown in Fig. 6. It must be kept in mind that only those losses as given by equation (11), using the same general circuit constants used in equations (5) to (10) for determining the circle diagram, should be so added in order to determine the generator conditions. The line RS shows the phase shift of the load or change of power-factor along the line from receiver to generator. This phase shift will be proportional to the distance along the transmission line except for the sudden phase shift of the transformers at the ends if they have been included.

LOSS CIRCLE DIAGRAM

The loss formula, (11), may be put in the form of a circle and plotted in connection with the regular circle diagram*. This it seems desirable to do, as the losses neglected when using the general circuit constants are practically constant for different loads, so that the most economical point of operating the line can be determined from the diagram. The centers and radii of the loss circles will be given by:

$$P_R = -\frac{t}{2v} E_R^2$$

$$Q_R = -\frac{w}{2v} E_R^2$$

$$Radius = E_R \sqrt{\frac{L_R}{v} + (t^2 + w^2 - 4uv)\frac{E_R^2}{4v^2}}$$

where the derivation and nomenclature is fully explained in the appendix. It is to be noted that the position of the loss circles varies for changes in the receiver voltage and that this must be taken into account for different assumptions in regulation.

EFFICIENCY CIRCLE DIAGRAM

The transmission efficiency η can be expressed as the ratio of the receiver power to the receiver power plus the losses, and may similarly be expressed in the form of a circle which can be plotted on the regular circle diagram. The center and radius of the efficiency circles will be given by:

$$P_R = -\frac{E_R^2}{2v}\left[t - \left(\frac{100}{\eta} - 1\right)\right]$$

$$Q_R = -\frac{w}{2v} E_R^2$$

$$Radius = \frac{E_R^2}{2V}\sqrt{\left[t - \left(\frac{100}{\eta} - 1\right)\right]^2 + w^2 - 4uv}$$

where the derivation and nome nclature is fully explained in the appendix. It is to be noted that the ordinate Q_R for the position of the centers of the circles is the same for both efficiency and loss circles, and may be called the line of minimum loss. Also the variation of the receiver voltage effects the position of the circles as before, except that the radius is effected as the square of the voltage.

NEGATIVE POWER

An analysis of the voltage-power expression shows that the load conditions for a negative load at the receiver or supply are the same as for a positive load at the supply or receiver with the same voltages as the points where the power is supplied or received. This means that the same circle diagram for receiver or supply can be used for positive and negative power with the voltages fixed at the ends regardless of the flow of power. The same is true of the loss circles, of which there are two sets, one for the supply and one for the receiver end.

An analysis of the efficiency expressions shows that there are four sets of circles, two for the supply end and two for the receiver end for positive and ne-

*In a manner suggested by Monsieur G. Darieus, Consulting Engineer.

gative power respectively. The two expressions for positive power at the supply and receiver ends are given in the appendix by equations (14) and (15). The other two expressions for negative power are the same, except that with negative power the term for percent loss is negative, that is the terms $\left(\frac{100}{\eta}-1\right)$ for the receiver end will now be $\left(1-\frac{100}{\eta}\right)$, and $\left(1-\frac{\eta}{100}\right)$ for the supply end will be $\left(\frac{\eta}{100}-1\right)$

COMPLETE CIRCLE DIAGRAM

The circle diagram as now modified may or may not include transformers and will appear as shown in Fig. 7, from which the loss and efficiency can be obtained directly, interpolating where necessary. For example, a load of such magnitude and power-factor that it would be represented by the point at the intersection of the 2000 kw loss and 95 percent efficiency circles, would have a loss of 2000 kw and an efficiency of 95 percent. In the example given a load of 50 000 Kw, with 97 percent leading power-factor to maintain constant receiver voltage, can be transmitted with an efficiency of 94.5 percent having 3000 Kw loss as read from the curves. This shows how closely these values may be interpolated.

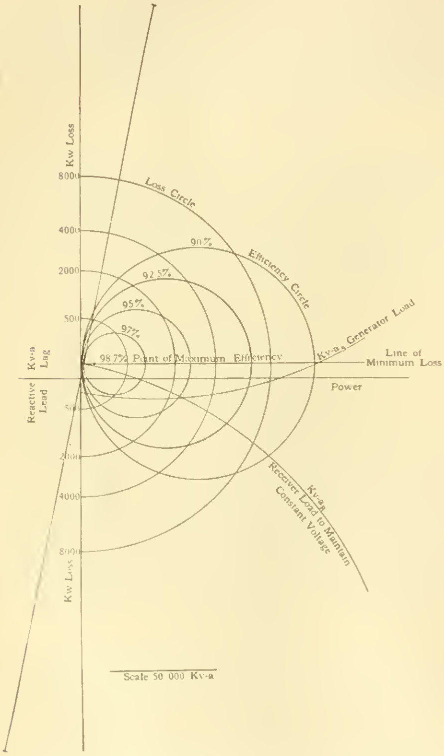

FIG. 7—COMPLETE CIRCLE DIAGRAMS

Showing loss and efficiency circles for a constant receiver voltage.

In order to simplify the computations, the loss and efficiency circles need only be calculated for the voltage regulation giving a condenser of normal design and minimum size, or for voltage conditions fixed by some other factor of operation. Since the loss and efficiency circles may be developed in terms of either generator or receiver quantities, as shown in the appendix, they may be computed for whichever end the voltage conditions are considered constant, and in this way the effects of different voltage regulations will be reduced.

The point of disappearance of the efficiency circles on the diagram is the point where the radius becomes equal to zero and is the point of maximum efficiency of the line. This may be expressed as follows:

$$P_R = \pm \frac{E_R^2}{2v}\sqrt{4uv - w^2}$$

$$Q_R = -\frac{w}{2v} E_R^2$$

The derivation is fully explained in the appendix.

The efficiency circles bring out very clearly in the diagram, without further derivation of any formula, that, in general, a transmission system is the most efficient when operating at a lagging power-factor. The efficiency increases very rapidly at first with small low power-factor loads, then reaches a maximum and falls off gradually to full load, which is probably at leading power-factor in order to maintain the regulation. Similarly, for a constant impedance load, the variation of efficiency with power-factor is rapid at first, increasing with low lagging power-factors, reaching a maximum before reaching unity power-factor and gradually decreasing at an ever increasing rate as the power-factor decreases leading.

For a transmission system to operate at the most efficient point throughout the range of load with constant receiver voltage, it is necessary to operate with compensated voltage regulation at the generator in such a way that the receiver load conditions will coincide with the line of minimum loss. With constant generator voltage, the receiver voltage should be decreased at light loads and increased at heavy loads. In either case, the generator voltage will be approximately equal to the receiver voltage at no load.

CONCLUSIONS

The diagram, as modified, shows, as completely as possible by any known method, all the solutions of generator and receiver conditions, losses and efficiency, with or without transformers, to a degree of accuracy approached only by complete numerical solutions. While at first the computations may appear complicated, fully half of them are simple arithmetic calculations which are relatively simple in comparison to the manipulation of the complex quantities which must be used in solving for the general circuit constant or making a similar mathematical solution.

The basis of the graphical method which has been covered by this article is exact, and the only errors involved are those of calculation or certain approximations which have previously been pointed out in obtaining the necessary constants, and the laying out and reading of the scalar quantities. This method gives a multiplicity of answers for arriving at a concrete conclusion, whereas the same amount of work through a mathematical method would accomplish the solution of only one particular set of conditions. A further advantage of this method is that it points out the best conditions of operation in regard to voltage in order to obtain the maximum efficiency and the most economical balance of efficiency.

APPENDIX

In Table III, p. 358 of the JOURNAL for August 1921, formulas are given for determining the general circuit constants, A_0, B_0, C_0 and D_0 for practically every circuit condition. By similar methods of solution, constants for any type of network can be obtained. These constants have been defined in this article by equations (1) to (4) and for simplification in the following equations can be expressed as follows:—

$$A_0 = a_1 + ja_2$$
$$B_0 = R_0 + jX_0$$
$$C_0 = g_0 + jb_0$$
$$D_0 = d_1 + jd_2$$

CIRCLE DIAGRAM*

From equation (1) can be derived the usual circle diagram in terms of the load conditions at the receiver as follows:—

$$E_s \overline{E}_s = (A_0 E_r + B_0 I_r)\ (\overline{A}_0 \overline{E}_r + \overline{B}_0 \overline{I}_r)$$

This expression, when expanded and simplified, gives the equation of a circle:—

$$(P_R + A_R)^2 + (Q_R + B_R)^2 = C_R^2$$

Where:—

$$A_R = \left(\frac{A_0\overline{B}_0 + \overline{A}_0 B_0}{2B_0\overline{B}_0}\right) E_R^2 = \left(\frac{a_1 R_0 + a_2 X_0}{R_0^2 + X_0^2}\right) E_R^2 = l\, E_R^2$$

$$B_R = j\left(\frac{A_0\overline{B}_0 - \overline{A}_0 B_0}{2B_0\overline{B}_0}\right) E_R^2 = \left(\frac{a_1 X_0 - a_2 R_0}{R_0^2 + X_0^2}\right) E_R^2 = mE_R^2$$

$$C_R = \frac{E_S E_R}{B_0\overline{B}_0} = \frac{E_S E_R}{\sqrt{R_0^2 + X_0^2}} = nE_S E_R$$

When P_R and Q_R are expressed in Kv-a, the constants A_R, B_R *and* C_R must be divided by 1 000 according to equations (5) to (7).

Similarly, equation (3) can be expanded into a circle diagram in terms of the load conditions at the supply end, as follows:—

$$E_r \overline{E}_r = (D_0 E_s - B_0 I_s)\quad (\overline{D}_0 \overline{E}_s - \overline{B}_0 \overline{I}_s)$$

This expression when expanded and simplified gives the equation of a circle:—

$$(P_S - A_S)^2 + (Q_S - B_S)^2 = C_S^2$$

Where:—

$$A_S = \left(\frac{D_0\overline{B}_0 + \overline{D}_0 B_0}{2\, B_0\overline{B}_0}\right) E_S^2 = \left(\frac{d_1 R_0 + d_2 X_0}{R_0^2 + X_0^2}\right) E_S^2 = l'\, E_S^2$$

$$B_S = j\left(\frac{D_0\overline{B}_0 - \overline{D}_0 B_0}{2\, B_0\overline{B}_0}\right) E_S^2 = \left(\frac{d_1 X_0 - d_2 X_0}{R_0^2 + X_0^2}\right) E_S^2 = m' E_S^2$$

$$C_S = \frac{E_S E_R}{B_0\overline{B}_0} = \frac{E_S E_R}{\sqrt{R_0^2 + X_0^2}} = nE_S E_R = C_R$$

Reference to equations (5) to (10) gives the supply and receiver circle diagram constants with phase to neutral voltages quantities when P and Q are expressed in kv-a. Fig. 1 shows the way in which the diagram may be plotted and the quadrants in which the respective circles lie.

*Where capital subscripts are used in this article line quantities are referred to and small subscript, phase quantities (phase to neutral). P and Q are expressed in watts and volt-amperes respectively.

LOSS EQUATIONS

The losses of a transmission network are equal to the difference of the power supplied to it and that delivered. In other words, the loss is equal to the difference of the real components in the following expression with E_R used as a reference vector:—

$$\textit{Total loss} = 3\, E_s \overline{I}_s - 3\, E_r \overline{I}_r = (P_S - P_R) + j\ (Q_S - Q_R)$$

$$P_S = \left(\frac{B_0\overline{C}_0 + \overline{B}_0 C_0}{2} + \frac{A_0\overline{D}_0 + \overline{A}_0 D_0}{2}\right) P_R + \left(\frac{A_0\overline{C}_0 + \overline{A}_0 C_0}{2}\right) E_R^2 +$$
$$3\left(\frac{B_0\overline{D}_0 + \overline{B}_0 D_0}{2}\right) I_r + j\left(\frac{A_0\overline{D}_0 - \overline{A}_0 D_0}{2} - \frac{B_0\overline{C}_0 - \overline{B}_0 C_0}{2}\right) Q_R$$

and $P_R = P_R$.

Then $P_S - P_R = \textit{total loss} = tP_R + uE_R^2 + 3vI_r^2 + wQ$.. which is the same as equation (11), where,—

$$t = \left(\frac{B_0\overline{C}_0 + \overline{B}_0 C_0}{2} + \frac{A_0\overline{D}_0 + \overline{A}_0 D_0}{2} - 1\right) = R_0 g_0 + X_0 b_0 + a_1 d_1 + a_2 d_2 - 1$$

$$u = \left(\frac{A_0\overline{C}_0 + \overline{A}_0 C_0}{2}\right) = a_1 g_0 + a_2 b_0$$

$$v = \left(\frac{B_0\overline{D}_0 + \overline{B}_0 D_0}{2}\right) = d_1 R_0 + d_2 X_0$$

$$w = -j\left[\frac{(B_0\overline{C}_0 - \overline{B}_0 C_0)}{2} - \frac{(A_0\overline{D}_0 - \overline{A}_0 D_0)}{2}\right]$$
$$= X_0 g_0 - R_0 b_0 + a_1 d_2 - a_2 d_1$$

An expression for transmission loss similar to equation (11) can be derived in terms of the load conditions at the supply end with E_S used as a reference vector.

$$\textit{Total loss} = -\, tP_S + u' E_S^2 + 3v' I_s^2 - w' Q_S \ldots \quad (12)$$

Where $u' = \left(\dfrac{D_0\overline{C}_0 + \overline{D}_0 C_0}{2}\right) = d_1 g_0 + d_2 b_0$

$$v' = \left(\frac{B_0\overline{A}_0 + \overline{B}_0 A_0}{2}\right) = a_1 R_0 + a_2 X_0$$

$$w' = -j\left[\frac{(B_0\overline{C}_0 - \overline{B}_0 C_0)}{2} + \frac{(A_0\overline{D}_0 - \overline{A}_0 D_0)}{2}\right]$$
$$= X_0 g_0 - R_0 b_0 + a_2 d_1 - a_1 d_2$$

The only difference in the two expressions is in the constants of the last three terms and the sign of the first and last terms and this can be explained by the fact that power supplied to the circuit is the same as a negative load so that the two equations are the same.* The fourth term of the two loss expressions involves reactive volt amperes, which has been previously defined in a foot note as positive for lagging and negative for leading.

It is to be noted that these constants simplify a great deal for a transmission line alone when leakage is neglected. For these conditions, the constants become:—

$$t = o \qquad \text{(an approximation)}$$
$$u = a_2 b_0 \qquad = u'$$
$$v = a_1 R_0 + a_2 X_0 \qquad = v'$$
$$w = -\, R_0 b_0 \qquad = w'$$

LOSS CIRCLE DIAGRAM

For the purpose of determining the loss circle diagram, equation (11) may be written as follows:—

$$L_R = t\, P_R + uE_R^2 + v\,\frac{(P_R^2 + Q_R^2)}{E_R^2} + w\, Q_R \ldots\ldots (13)$$

This may be expanded and symplified to give the equation of a circle:—

$$\left(P_R + \frac{t}{2v} E_R^2\right)^2 + \left(Q_R + \frac{w}{2v} E_R^2\right)^2 =$$
$$\left(E_R\sqrt{\frac{L_R}{v} + (t^2 + w^2 - 4\, uv)\,\frac{E_R^2}{4\, v^2}}\right)^2$$

*It should be noted that the only difference in the constants of the last three terms is with regard to the interchange of the A_0 and D_0 constants. The reason for this may be seen in equations (1) to (4) where A_0 and D_0 were originally interchanged. This also applies to the difference of the l, m and l', m' constants.

from which the position of the center and the radius are self-evident and are as given in the main part of this article.

A similar set of circles for the supply end can be determined from equation (12) or written from similarity to the equation above by changing the signs of the t and w constants, changing the subscripts R to S and changing u, v, w, to u', v', w'. This gives:—

$$\left(P_S - \frac{t}{2v'} E_S^2\right)^2 + \left(Q_S - \frac{w'}{2v'} E_S^2\right)^2 = \left(E_S \sqrt{\frac{L_S}{v'} + (t^2 + w'^2 - 4u'v')\frac{E_S^2}{4v'^2}}\right)^2$$

EFFICIENCY CIRCLE DIAGRAM

For the purpose of determining the equation for the efficiency diagram the transmission losses may be expressed as $P_R\ (100/\eta - 1)$, where η is the percent efficiency, and substituted in equation (13) for L_R. The resulting equation may be expanded and simplified to give the equation of a circle.

$$\left[P_R + \frac{E_R^2}{2v}\left(t - \left(\frac{100}{\eta} - 1\right)\right)\right]^2 + \left[Q_R + \frac{w}{2v}E_R^2\right]^2 = \left[\frac{E_R^2}{2v}\sqrt{\left(t - \left(\frac{100}{\eta} - 1\right)\right)^2 + w^2 - 4uv}\right]^2 \quad \ldots\ldots\ldots (14)$$

from which the location of the center and the radius is as given in the main part of this article.

A similar set of circles for the supply end can also be written from similarity by changing the subscripts R to S, changing the signs of the t and w constants and changing u, v, w to u', v', w', and also remembering that the expression $(100/\eta - 1)$ now becomes $(1 - \eta/100)$. This gives:—

$$\left[P_S - \frac{E_S^2}{2v'}\left(t + \left(1 - \frac{\eta}{100}\right)\right)\right]^2 + \left[Q_S - \frac{w'}{2v'}E_S^2\right]^2 = \left[\frac{E_S^2}{2v'}\sqrt{\left(t + \left(1 - \frac{\eta}{100}\right)\right)^2 + w^2 - 4v'u'}\right]^2 \quad \ldots\ldots\ldots (15)$$

The point of maximum efficiency is the point where the radius becomes equal to zero. This gives from equations (14) and (15):—

$$\pm\sqrt{4uv - w^2} = \left(t - \left(\frac{100}{\eta} - 1\right)\right) \text{ and } \pm\sqrt{4u'v' - w'^2} = -\left(t + \left(1 - \frac{\eta}{100}\right)\right).$$

Substituting in equation (14) gives:—

$$\left[P_R \pm \frac{E_R^2}{2v}\sqrt{4uv - w^2}\right]^2 + \left[Q_R + \frac{w}{2v}E_R^2\right]^2 = 0$$

and in equation 15 gives:—

$$\left[P_S \pm \frac{E_S^2}{2v'}\sqrt{4u'v' - w'^2}\right]^2 + \left[Q_S - \frac{w'}{2v'}E_S^2\right]^2 = 0$$

Each of these equations has two solutions, one for positive power and the other negative power. The real points for positive power will fall in the first and fourth quadrants for the supply and receiver ends respectively as given by the above expressions, when considering the minus root of the radical in the first term. Somewhat more simplification in plotting can be obtained by expressing the above in a ratio of P to Q.

The j term is not involved in any of the final expressions for the circle diagrams because the constants l, l', m, m' n, t, u, u', v, v', w and w' have included it. P_R, P_S, Q_R, Q_S, E_R, E_S, I_r, and I_s should be taken as scalar quantities in these final expressions for the loss equations and the voltage-power, loss and efficiency diagrams.

The Dry Cell Radio Vacuum Tube

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THE owner of a radio receiving outfit is aware of the advantages to be obtained by using one or more vacuum tubes in the circuit, if other than very strong signals are to be heard, or if a loud speaking device is to be used. Many have foregone these advantages, however, on account of the expense or inconvenience of the accessories, particularly the battery necessary to supply the filament energy. As most tubes available have filaments requiring a current of from 0.6 to 1.0 ampere, at from four to six volts, a six volt storage battery has been the only satisfactory source. This has meant the presence of acids, an expensive battery and the necessity of charging at intervals.

A new tube has recently been developed, which makes the use of a storage battery unnecessary. Fig. 1 shows the tube reproduced to two-thirds actual size. It is somewhat smaller than most tubes and fitted with a base designed to prevent its being accidently placed in a socket supplied by a six volt battery and thereby having its filament ruined. This base is also designed to prevent the accidental connecting of the plate potential to the filament terminals.

The filament requires but 1.1 volt to operate and uses 0.2 ampere continuously. This means a power consumption of less than one fourth watt as compared with 3 to 5 watts in the ordinary tube filament. For this reason it is possible to operate the filament from a single dry cell and avoid the greater expense and trouble incident to the use of a storage battery. In addition to this advantage, a plate battery of 22 volts is sufficient for all work, except where the utmost in signal strength is required, in which case a plate potential of 30 volts will give slightly better results. A higher potential than this is never necessary and a potential above 22 volts is seldom needed, hence this tube makes unnecessary the use of a second B battery block, and the expense incident to it. Again, the tube is hard, so that the plate voltage adjustment is not critical, no adjustment being necessary on that account.

An idea of how long a dry battery should last in the service required by this tube, is given in Figs 2 and 3. In both cases it has been assumed that the tube is to be operated one hour out of each twenty-four Fig 4 is added to show how the power obtained from a single No. 6 dry cell will vary with the rate at which the dry cell is drawn upon. Thus, if several dry cells in series were used to supply a filament requiring 0.8 ampere, only five ampere-hours would be available from each cell before its voltage would have dropped to one volt at the end of a one hour run, while 22 ampere-hours would be available for supplying a filament requiring 0.2 amperes before the voltage would take a corresponding drop.

This information illustrates the wonderful possibilities of this tube in a portable receiving outfit. It

is probable that more such outfits were carried to camp during the summer of 1921 than during any previous season, in spite of the limitations imposed by a storage battery. This "dry cell" tube now makes it practica-

FIG. 1—NEW VACUUM TUBE REQUIRING LESS THAN 0.25 WATT FOR HEATING FILAMENT

ble for a party on an extended canoe trip into the wilds of Canada to carry with them a receiving set of small dimensions and weight, and of sufficient range to keep in touch with world affairs. With the present radiophone broad-casting of market and stock reports, and the Post Office Department's proposed extension of this method of announcement, it is not necessary

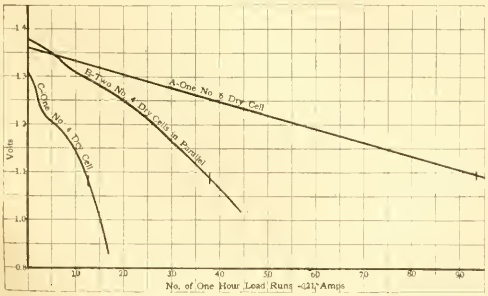

FIG. 2—VOLTAGES OF DRY CELLS AT THE ENDS OF SUCCESSIVE ONE-HOUR RUN

that a man become an expert at copying code in order to take advantage of such opportunities.

The advantage is not limited, however, to the portable set. In the home, a dry cell is always to be desired in preference to a storage battery, not only on the score of economy, but also because a dry cell may be located in any convenient place.

It is logical to ask how this great decrease in filament power consumption has been accomplished. The design of every essential element in the tube contributes to this end. Fig. 5 shows the interior arrangement and Fig. 6 the elements which go to make up this structure. The filament is of platinum, about one-eighth as thick as fine tissue paper, and one one-hundredth of an inch wide. This is coated with a very thin layer of certain oxides with the result that a special form of Wehnelt cathode is formed. This fila-

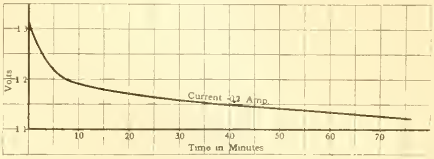

FIG. 3—DROP IN VOLTAGE DURING RUN OF A NO. 4 DRY CELL WHICH IS NEARLY EXHAUSTED

ment is welded to end supports for easy assembly, and is kept in position by the aid of a specially constructed and very flexible form of spring. This spring enables the filament to move freely in case of a severe jar, but otherwise to be held firmly in place. It results in an exceedingly rugged structure for so delicate a strip. The grid and plate are of the common forms except that very small and exact dimensions must be used. If accuracy and inspection were not carefully maintained, inoperative tubes would result. The assembly is centered about the electric welding machine, Fig 7, and this operation has been refined to a very high degree to make possible such products as are represented in this tube. The final operation in obtaining this tube is performed by the exhaust system.

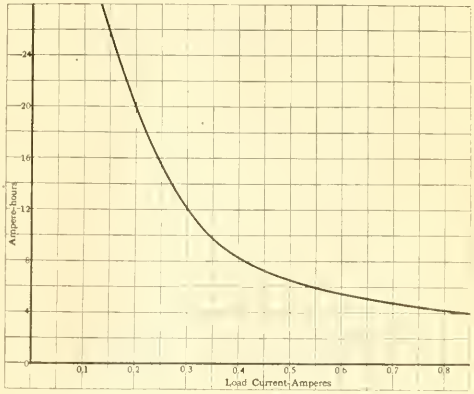

FIG. 4—POWER AVAILABLE FROM A NO. 6 DRY CELL WHEN OPERATED FOR ONE HOUR A DAY, WITH A FINAL VOLTAGE OF 1.1 VOLTS

Here special apparatus and special schedules have been developed to make possible a tube of high quality and uniformity.

A characteristic curve for this tube, Fig. 8 shows that the unusual filament and plate structure and dimensions have in no way produced undesirable varia-

tions in this curve. The amplification factor is approximately seven and a plate impedance of about 22 000 ohms is obtained, making it possible to insert this tube in any of the usual circuits designed for a low imped-

FIG. 5—ASSEMBLED ELECTRODES OF THE NEW VACUUM TUBE

ance tube, without fear of unsatisfactory operation.

In operation, the low voltage and power requirements of this tube make certain precautions necessary to the uninitiated user. The filament operates at a low red heat instead of at the bright point to which users of tungsten filament tubes are accustomed. If a six

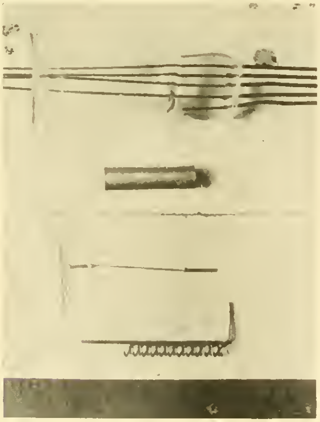

FIG. 6—PARTS OF THE NEW VACUUM TUBE

volt battery were to supply power to this filament with only the usual six ohm rheostat in series, the filament would have a very short life, since the rheostat would not have sufficient resistance to cut down the current to the proper value. At a bright yellow heat this filament will deteriorate rapidly, even though the inexperienced eye may consider it to be operating at a conservative temperature. It is necessary, therefore, until the operator is well acquainted with this tube, that he take special precautions to maintain the filament current at the lowest value which will give full signal

FIG. 7—ASSEMBLING THE PARTS ON AN ELECTRIC WELDING MACHINE

strength. The filament will give no warning, such as a bright light, or noise in the phones, when it is being operated beyond its proper temperature, so that the responsibility for a long filament life lies with the operator in making the proper rheostat adjustments, unless a ballast lamp is used. If this simple rule is followed, the user of this tube will find that he has a new device which will not only make good radio operation more

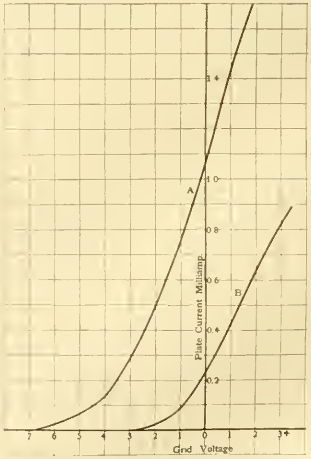

FIG. 8—CHARACTERISTIC CURVES OF PLATE CURRENTS AT TWO PLATE VOLTAGES

economical, but will enable him to enjoy it with much less attention to the accessories, and in places where he had not thought it possible to carry a set.

Changing Railway Substations from 25 to 60 Cycles

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WITH the development of large generating units and the increase in efficiencies, there has been a tremendous growth of the central station power companies in the past ten or fifteen years. As a result of this growth and increased efficiency of generation, many electric railways have found it expedient to purchase power and either sell or scrap their generating equipment. In a considerable portion of the United States, the standard frequency for lighting and power is 60 cycles. Numerous electric railways throughout the country generate at 25 cycles and use 25 cycle converting equipment in their substations. Where such a company, located in a 60 cycle power district, finds it expedient to purchase power, it is confronted with the problem of equipping its substations to utilize 60 cycle power.

Although in a few isolated cases it may prove economical to retain the 25 cycle converting apparatus and supply the system through frequency changers, it will usually be found advisable to make such changes as are necessary in the converting equipment to permit operation at 60 cycles. When such a change is contemplated the question arises as to how much of the 25 cycle equipment can be used and what changes, if any, will be required to make it suitable for 60 cycle operation.

Although it is not possible to formulate definite rules covering all cases, the principal considerations involved are outlined below and, in general, this outline will serve to indicate the conditions most frequently encountered.

SYNCHRONOUS CONVERTERS

In making such a change there is, quite naturally, a desire to rebuild the synchronous converters for 60 cycles. In a number of cases this problem has been invesigated, and it has not been found practicable to rebuild 25 cycle converters for 60 cycle operation. From an economic point of view, there is practically nothing to be saved in first cost. As a matter of fact, the expense involved is apt to result in a cost even higher than that of new 60 cycle units. This will be appreciated when it is realized that such a change necessitates the manufacture of special parts for the existing machines, as about the only parts of the 25 cycle units which can be used are the frames and bedplates and in some cases the bearing pedestals. Second, the possibilities of obtaining good operating characteristics are rather remote, as the old parts do not lend themselves particularly well to the design of a 60 cycle unit and, furthermore, it is impossible to include many of the improvements embodied in the modern 60 cycle converter which are so essential to its good performance.

The six-phase synchronous converter has become the standard for both 25 and 60 cycles, because of its higher efficiency and greater output for a given armature winding. Many three-phase and some two-phase converters were built before the development of the six-phase machine and quite a few of these machines are still in operation. Therefore, in substituting modern six-phase converters, several problems are encountered, relating to the proper alternating-current voltage and grouping of transformers, which are discussed in detail under the heading of transformers. Table I shows the theoretical no-load ratios between alternating-current and direct-current voltages in synchronous converters and also the values of alternating current per ring, expressed in percent of the corresponding direct current amperes.

TABLE I—VOLTAGE RATIOS AND ALTERNATING CURRENT AMPERES

No. of Phases	Rings	Approx. Ratio A. C. to D. C. Voltages	Approx. Amps. per Ring in Percent of D. C. Amperes
Single	2	0.71	150
Three	3	0.61	100
Two	4	0.71	75
Six (diametrical)	6	0.71	50
Six (double delta)	6	0.61	50

TRANSFORMERS

In general, a 25 cycle transformer of the type used in railway converter work, will deliver its rated kv-a, at its rated voltage on 60 cycles, without exceeding a safe temperature. With the same impressed voltage in each case, the core losses on 60 cycles will be less than on 25 cycles, due to the lower flux density. The copper losses will be somewhat higher on 60 cycles, due to the increased eddy current losses. However, the eddy current losses in the copper are usually but a small percentage of the total copper losses, and the increase generally may be neglected, as it is more than counter-balanced by the decrease in core losses.

Modern transformers for railway converter work are designed with approximately 15 percent reactance, except where this value is not suitable for parallel operation of the converter with existing converters. Many of the earlier transformers have relatively low reactance values, and when changed from 25 to 60 cycle operation, the reactance, which varies directly as

the frequency, will not be greater than 15 percent. Special attention must be given reactance values when parallel operation of converters is involved and occassionally it may be found necessary to install reactance coils in the leads of converters having unusually low reactance transformers. If the transformer reactance is unusually high when operated on 60 cycles, it is advisable to consult the manufacturer of the converter regarding its performance under such conditions.

The reactance of a transformer varies also as the square of the total number of turns in the coils. Therefore, if there are any full capacity, reduced voltage taps, on the high and low voltage windings, it may be possible to reduce the reactance, if necessary, by operating on suitable taps. In some cases this can be done without affecting the ratio of transformation. Naturally this method has limitations beyond which it is unsafe to go, but generally any full capacity taps may be used.

If the 25 cycle converter to be replaced is a six-phase machine, of course the voltage of the existing transformers will be correct for the standard six-phase, 60 cycle unit. However, if a three-phase machine is being replaced, the voltage delivered by its transformers will be too low for the operation of the six-phase, 60 cycle unit, assuming that the same direct-current voltage is to be maintained. It may be possible to obtain the necessary increase in voltage by operating the transformers on reduced voltage taps on the high-voltage winding. However, if suitable taps on the high-voltage winding are not available, and it is not practicable to bring out such taps, the converter may be arranged for three-phase operation. This may be done by removing the taps to the armature winding from alternate collector rings and paralleling each of the remaining rings with an idle one. This leaves the armature connected to the collector rings in the proper three-phase relationship and provides the necessary brush capacity for three-phase operation.

It should be realized that three-phase operation of a given six-phase converter reduces its thermal capacity. Its ability to commutate momentary loads, however, is not affected. Therefore in interurban work, where the size of the substation units is determined on the basis of the heaviest momentary peaks, and where the integrated loads are but a small percentage of the converter ratings, the reduction in thermal capacity is of small consequence. In city work, however, where converters are fully loaded for long periods followed by overloads of several hours duration, the reduction in thermal capacity is of importance, and should be given careful consideration.

If the converter being replaced is a two-phase machine, its transformers are wound for the proper voltage for a six-phase diametrically-connnected converter but, in order to obtain the full capacity of the existing transformers and the new six-phase converter it will be necessary to install a third transformer. This results in an increase of 50 percent in transformer capacity and permits the installation of a correspondingly larger converter. This may prove desirable in some cases, while in others the cost may be prohibitive. Although it is possible to operate the converter on two transformers, its thermal capacity will be lowered approximately 35 percent. The commutation of the converter will not be affected, within the range of the usual ratings, and therefore in interurban work, this arrangement may prove quite satisfactory. In city work, however, the better plan is to add a third transformer to each bank. It is of interest to note that in a station having three, 25 cycle, two-phase converters, the transformers could be re-grouped into two three-phase banks and two larger converters installed without in any way affecting the station capacity. With the larger converters, heavier switching equipment probably would be necessary.

Where the converters being replaced are of the alternating-current self-starting type, the starting taps on the existing transformers should be satisfactory for starting the 60 cycle converters. However, if the old 25 cycle converters are motor started, the existing transformers probably will not have starting taps. The modern alternating-current self-starting converter requires approximately one-third voltage at the collector rings when starting. In many existing transformers it may be difficult, or impracticable to bring out one-third voltage taps on the low-voltage windings. In most cases, however, it is not difficult to bring out 50 percent taps from cross-over connections between the low-voltage coils, which will be satisfactory for starting the converter, provided the increased kv-a drawn in starting does not produce too great fluctuations in the transmission voltage. If the increase in kv-a resulting from the higher starting voltage is objectionable, it may be limited by inserting resistance or reactance in the converter leads in starting.

Direct-current starting may be resorted to, if direct current power is always available and if the direct-current voltage is fairly constant, so that synchronizing is possible. If the direct-current supply fluctuates badly, it may be desirable to bring the machine up to approximate speed and, after opening the direct-current switches, connect the converter to the transformers through a suitable reactance, which may be short-circuited or cut out when the machine has pulled into synchronism.

CURRENT AND POTENTIAL TRANSFORMERS

In current transformers, a change in frequency from 25 to 60 cycles reduces the magnetizing current, thereby tending to reduce the ratio and phase errors. In a potential transformer the change from 25 to 60 cycles affects the accuracy but slightly. In fact, both current and potential transformers are so accurate that the variation in error, due to a change in frequency from 25 to 60 cycles, usually is negligible.

INSTRUMENTS AND RELAYS

Most 25 cycle instruments and relays in service at the present time will require re-calibration for use on 60 cycles. The expense of the re-calibration is small, especially if the operating company is equipped to handle such work. Even though the instruments and relays are returned to the factory for re-calibration, the cost is low compared with that of new apparatus.

SWITCHBOARDS

The change in frequency in itself will not affect the switchboard or the wiring, but the use of a six-phase, alternating-current, self-starting converter may require some changes. For example if a motor-started converter is being replaced by a six-phase, alternating-current self-starting unit, the motor switch and wiring, main alternating-current converter switch and the synchroscope, synchronizing receptacles and wiring may be removed. A three-pole, double-throw, starting switch and a two-pole, double-throw, field reversal switch, with discharge clip and discharge resistance, must be installed. In some cases this apparatus, together with a small differential voltmeter for determining the converter polarity, may be mounted on a separate panel located near the transformers, thus simplifying the work and reducing the amount of cable and wire required.

GENERAL

It should be realized that in changing from 25 cycle operation additional operating problems are presented. As is well known, the design problems in a 25 cycle converter are simpler than in a 60 cycle converter, since the design inherently allows greater clearances and creepage distances and, in general, fewer space limitations are encountered. For the best results, therefore, it is important that the 60 cycle machines be kept thoroughly clean, the commutator and brushes in good condition and the spacing and alignment of brushholders properly maintained. Also it is important that proper protective devices be provided and that these devices be carefully adjusted and kept in good working order. From the above the impression should not be obtained that the 60 cycle converter is not a thoroughly satisfactory unit, as the contrary is proven by the large number of 60 cycle units in satisfactory service. It is, however, intended to point out that the different conditions must be properly handled in order to obtain the best results.

Many of the earlier converters are quite liberally rated, as design problems in those days were not so well understood as they are today, and rather large factors of safety were used. Modern synchronous converters closely duplicate the calculated performance, with the result that a nameplate rating of say 500 kw, means that the machine will deliver that output, with such overload as may be specified, with only a reasonable margin of safety. Therefore in choosing new units, the actual load conditions, rather than the nameplate rating of the existing machines, should govern the size of units selected.

A sychronous converter should be provided with an automatic oil circuit breaker connected, preferably, in the hightension leads of the transformers. The oil circuit breaker should be equipped with instantaneous overload trip, low-voltage release attachment and an auxiliary switch attachment. The latter device should be connected so as to short-circuit the low-voltage coil of the direct-current machine circuit breaker, thus insuring that the machine will be disconnected from the direct-current bus whenever the alternating-current breaker opens.

The proper setting of the alternating and direct-current machine circuit breakers is of great importance if the best results are to be obtained. The modern converter will commutate large momentary currents, provided the direct-current machine circuit breaker does not open, while almost invariably the converter will flash at no greater loads, if the direct-current machine circuit breaker opens. Therefore it is desirable to have a high setting of the direct-current machine circuit breaker, particularly where there are several feeder circuits. The feeder circuit breakers should be equipped with instantaneous trip and set sufficiently low to permit selective action between them and the direct-current machine circuit breaker, so as to prevent the entire load being cut off the converter instantaneously.

In smaller stations, where there are no feeder panels, the tendency is toward making the direct-current circuit breaker non-automatic and protecting the converter entirely by means of the oil circuit breaker The direct-current circuit breaker then is equipped only with a low-voltage release coil, which is used to interlock with the oil circuit breaker, as previously mentioned.

In large stations, the converter capacities in service are usually great enough to commutate most short-circuits on the distribution system, and selective action between the feeder breakers and machine breakers is not at all difficult to obtain.

A synchronous converter also should be equipped with a direct-current reverse-current relay, overspeed device and power-factor meter, all of which are essential to the proper protection of the machine.

The importance of having some resistance between the converter and the trolley is now generally recognized. This may be most easily accomplished by removing the feeder taps near the station. Obviously, the distance to the first feeder tap will vary, depending on the size of feeders, capacity of the converter, capacity of the generating system and other factors, but in any case, feeder taps close to the station should be removed and the distance between the station and the first feeder tap increased until flashing from this source is eliminated. Generally, this distance, for 600 volt interurban systems, will not be less than 2000 feet.

Electrical Characteristics of Transmission Circuits-XVI

Phase Modifiers for Voltage Control

WM. NESBIT

WITH alternating-current transmission there is a voltage drop resulting from the resistance of the conductors, which is in phase with the current. In addition there is a reactance voltage drop; that is a voltage of self-induction generated within the conductors which varies with and is proportional to the current, and may add to or decrease the line voltage. If the line is long, the frequency high or the amount of power transmitted large, this induced voltage will be large, influencing greatly the line drop. By employment of phase modifiers the phase or direction of this induced voltage may be controlled so that it will be exerted in a direction that will result in the desired sending end voltage.

A certain amount of self-induction in a transmission circuit is an advantage, allowing the voltage at the receiving end to be held constant under changes in load by means of phase modifiers. It may even be made to reduce the line voltage drop to zero, so that the voltage at the two ends of the line is the same for all loads. Self-induction also reduces the amount of current which can flow in case of short circuits, thus tending to reduce mechanical strains on the generator and transformer windings, and making it easier for circuit breaking devices to function successfully. On the other hand, high self-induction reduces the amount of power which may be transmitted over a line and may, in case of lines of extreme length, make it necessary to adopt a lower frequency. It also increases the capacity of phase modifiers necessary for voltage control. High reactance also increases the surge overvoltage that a given disturbance will set up in the system.

On the long lines, the effect of the distributed leading charging current flowing back through the line inductance is to cause, at light loads, a rise in voltage from generating to receiving end. At heavy loads, the lagging component in the load is usually sufficient to reverse the low-load condition; so that a drop in voltage occurs from generating to receiving end. The charging current of the line is, to a considerable extent, an advantage; for it partially neutralizes the lagging component in the load, thus raising the power-factor of the system and reducing the capacity of synchronous condensers necessary for voltage control.

The voltage at the receiving end of the line should be held constant under all loads. To partially meet this condition, the voltage of the generators could be varied to a small extent. On the longer lines, however, the voltage range required of the generators ... be necess... be too great to permit regulation in this manner. In such cases, phase modifiers operating in parallel with the load are employed. The function of phase modifiers is to rotate the phase of the current at the receiving end of the line so that the self-induced voltage of the line (always displaced 90 degrees from the current) swings around in the direction which will result in the desired line drop. In some cases a phase modifier is employed which has sufficient capacity not only to neutralize the lagging component at full load, but, in addition, to draw sufficient leading current from the circuit to compensate entirely for the ohmic and reactance voltage drops of the circuit. In this case, the voltage at the two ends of the line may be held the same for all loads. This is usually accomplished by employing an automatic voltage regulator which operates on the exciter fields of the phase modifier. The voltage regulator may, if desired, be arranged to compound the substation bus voltage with increasing load.

CHECKING THE WORK

A most desirable method of determining line performance is by means of a drawing board and an engineer's scale. A vector diagram of the circuit under investigation, with all quantities drawn to scale, greatly simplifies the problem. Each quantity is thus represented in its true relative proportion, so that the result of a change in magnitude of any of the quantities may readily be visualized. Graphical solutions are more readily performed, and with less likelihood of serious error than are mathematical solutions. The accuracy attainable when vector diagrams are drawn 20 to 25 inches long and accurate triangles, T squares, straight edges and protractors are employed is well within practical requirements. Even the so-termed "complete solution" may be performed, graphically with ease and accuracy. A very desirable virtue of the graphical solution which follows is that it exactly parallels the fundamental, mathematical solution. For this reason this graphical solution is most helpful even when the fundamental mathematical solution is used, for it furnishes a simple check against serious errors. The result may be checked graphically after each individual mathematical operation by drawing a vector in the diagram paralleling the mathematical operation. Thus, any serious error in the mathematical solution may be detected as soon as made.*

*A method of checking arithmetical operations which requires little time and is an almost sure preventative of errors is that known as "casting out the nines." This method is given in most older arithmetics but has been dropped from many of the modern ones. A complete discussion is given in Robinson's "New Practical Arithmetic" published by The American Book Company.

When converting a complex quantity mathematically from polar to rectangular co-ordinates, or vice versa, the results may readily be checked by tracing the complex quantity on cross-section paper and measuring the ordinates and polar angle, or for approximate work the conversion may be made graphically to a large scale. For instance, in using hyperbolic functions, polar values will be required for obtaining powers and roots of the complex quantity. For approximate work much time will be saved by obtaining the polar values graphically.

In the graphical solution of line performance it will usually be desirable to check the line loss by a mathematical solution in cases which require exact loss values. Since the line loss may be five percent or less of the energy transmitted, a small error in the overall results might correspond to a large error in the value of the line loss.

EFFECT OF TRANSFORMERS IN THE CIRCUIT

Usually long transmission circuits have transformers installed at both ends of the circuit and one or more phase modifiers in parallel with the load. Such a transmission circuit must transmit the power loss of the phase modifiers and of the receiver transformers. In addition to this power loss, a lagging reactive current is required to magnetize the transformer iron. A complete solution of such a composite circuit (generator to load) requires that the losses of the phase modifiers and transformers be added vectorially to the load at the point where they occur so that their complete effect may be included in the calculation of the performance of the circuit. A complete solution also requires that three separate solutions be made for such a circuit.* First with the known or assumed conditions at the load side of the lowering transformers the corresponding electrical conditions at the high voltage side of the transformers is determined by the usual short line impedance methods. With the electrical conditions at the receiving end of the high-tension line thus determined, the electrical conditions at the sending end of the line are determined by one of the various methods which take into account the distributed quantities of the circuit. With the electrical condition at the sending end thus determined the electrical conditions at the generating side of the raising transformers are determined. The above complete method of procedure, is tedious if carried out mathematically, but if carried out graphically is comparatively simple.

It is the general practice to neglect the effect of condenser and lowering transformer loss in traveling over the line, but to add this loss to the loss in the high-tension line after the performance has been calculated. If the loss in condensers and lowering transformers is five percent of the power transmitted the error in the calculated results would probably be less than 0.5 percent, a rather small amount.

*A method for calculating a transmission line with transformers at each end in one solution is given in the articles by Messers. Evans and Sels in the JOURNAL for July, August, September, *et seq.* 1921.

In order to simplify calculations, it is the general practice to consider the lumped transformer impedance as though it were distributed line impedance by adding it to the linear constants of the line and then proceeding with the calculations as though there were no transformers in the circuit. This simplifies the solution but at the expense of accuracy, particularly if the line is very long, the frequency high or the ratio transformer to line impedance high. This simplified solution introduces maximum errors of less than two percent in the results for a 225 mile, 60-cycle line.

It has been quite general practice to disregard the effect of the magnetizing current consumed by transformers. The magnetizing current required to excite transformers containing the older transformer iron was about two percent and therefore its effect could generally be ignored. Later designs of transformers employ silicon steel, and their exciting current varies from about 20 percent for the smaller of distribution type transformers, to about 12 percent on transformers of 100 kv-a capacity and about five percent for the very largest capacity transformers. The average magnetizing current for power transformers is between six and eight percent. This magnetizing current is important for the reason that it is practically in opposition to the current of over-excited phase modifiers used to vary the power-factor. If in a line having 100 000 kv-a transformer capacity at the receiving end, the magnetizing current is five percent, there will be a 5000 kv-a lagging component. If the capacity of phase modifiers required to maintain the proper voltage drop under this load is 50 000 kv-a the lagging magnetizing component of 5000 kv-a will subtract this amount from the effective rating of the phase modifiers, with a resulting error of ten percent in the capacity of the phase modifiers required.

In the diagrams and calculations which follow, the transformer leakage, consisting of an in-phase component of current (iron loss) and a reactive lagging component of current (magnetizing current), is considered as taking place at the low-tension side of the transformers. A more nearly correct location would be to consider the leak as at the middle of the transformer, that is, to place half the transformer impedance on each side of the leak. To solve such a solution it would be necessary to solve two complete impedance diagrams for the transformers at each end of the circuit. The gain in accuracy of results would not, for power transmission lines, warrant the increased arithmetical work and complication necessary.

In the case of lowering transformers, it would seem that the magnetizing current would be supplied principally from synchronous machines connected to the load. If phase modifiers are located near the lowering transformers, the transformers would probably draw most of their magnetizing current from

them rather than from the generators at the distant end of the line. Partly for this reason, but more particularly for simplicity, the leak of the lowering transformers will be considered as taking place at the load side of the transformers. On this basis we first current also from the low side; that is from the generators. Both the complete and the approximate methods of solving long line problems which follow, include the effect of not only the magnetizing current consumed by the transformers, but also the losses in

TABLE V—COMPARISON OF RESULTS AS OBTAINED BY FIVE DIFFERENT METHODS OF CALCULATIONS

76,000 KW (88,236 KV-A AT 86% PF) 3 PHASE 60 CYCLES RECEIVER VOLTAGE HELD CONSTANT AT 220 KV 60 000 KV-A CONDENSER AT RECEIVING END

LENGTH OF TRANSMISSION 226 MILES ALL TABULATED VALUES REFERRED TO NEUTRAL

Area in Circular Mils	Method*	Receiving End to Neutral: Low Tension Side of Transformers: Volts E_{LN}	Amps I_L+I_C	PF_L Lead	High Tension Side of Transformers: Volts E_{RN}	Amps I_R	PF_R Lag	Sending End to Neutral: High Tension Side of Transformers: Voltage E_{SN}	%	Current I_S	%	PF_S Lead	Low Tension Side of Transformers: Voltage E_{GEN-N}	%	Current I_{GEN}	%	PF_{GEN} Lead	Losses in KW to Neutral: Lowering Transformers: Iron	Copper	Condenser	High Tension Line: KW_N	Loss in % of KW_L	Raising Transformers: Iron	Copper	Total Loss: KW.	Loss in % of KW_L
605 000	A	127020	2023	9990	127 556	2049	9963	129 090	100	2278	00	9377	26920	100	2261	100	9749	235	130	666	542	616	235	[illegible]	[illegible]	[illegible]
..	B		..	..				124 247	963	2365	1039	9335						..	..		1634	653		[illegible]	3078	23
..	C			..									124 657	982	2323	1028	95 [illegible]	..	..	..	1583	633	..	[illegible]	[illegible]	[illegible]
..	D		..	..				126783	984	2287	1004	9432						..	..		1553	621		[illegible]	2985	[illegible]
..	E	..		..									12753	1005	2246	993	9587	..	..	..	1510	604	..	160	2936	1174
715 500	A	..	..	..	127 556	2049	9963	127911	100	2287	00	9350	125 668	100	2266	100	9736	..	..		1320	528	..	66	2752	[illegible]
..	B			..				123 041	962	2375	1039	9309						..	..	..	1408	563	..	8	2854	1142
	C			..									123 409	982	2331	1028	9493	..	..		1338	535	..	[illegible]	[illegible]	[illegible]
..	D	..	..	..				25 5[illegible]6	982	2297	1004	9409						..	..	..	1349	540	..	68	2783	[illegible]
..	E	..	..	..									126 292	1005	2254	995	9567	..	..	..	1273	509	..	62	2701	[illegible]
795 000	A	..	..	..	127 556	2049	9963	127 196	100	2297	100	9333	124 909	100	2274	100	9724	..	..		1192	477	..	167	2625	1050
	B	..	..	..				122 313	962	2380	1038	9294						..	..		1260	504	..	181	2707	1083
	C			..									122 648	982	2335	1027	94 80	..	..	..	1177	471	..	174	2617	[illegible]
..	D	..	..	..				24 846	981	2302	1004	9394						..	..	..	1198	479	..	169	2633	[illegible]
..	E	..	..	..									25 532	005	2258	99.3	9555	..	..		126	450	..	162	2554	[illegible]
954 000	A	..	..	..	127 556	2049	9963	126 [illegible]32	100	2304	100	9293	123 740	100	2284	100	9699	..	..		976	390	..	169	[illegible]	964
..	B	..		..				121 212	961	2394	1039	9255						..	..		1059	423	..	183	2508	1003
..	C	..		..									121 488	982	2351	1029	9451	..			1020	408	..	177	2463	982
..	D	..	..	..				123 737	981	2315	1005	9358						..			1014	405	..	170	2450	980
..	E	..		..									124 368	100.5	2273	995	9531	..	..		984	393	..	165	2415	966

**A*—Transformer impedances treated as lumped at the ends of the line. This is the most nearly accurate of the five methods. It is referred to in the text as the complete solution.

B—This assumes the impedance of the lowering transformers as line impedance. It takes no account of the leakage of the lowering transformers.

C—This assumes the impedance of both lowering and raising transformers as line impedance—It takes no account of the leakage of the lowering and raising transformers.

D—This is the same as *B* except that the leakage of the lowering transformers has been added to the load—It is referred to in the text as the approximate solution.

E—This is the same as *C* except that the leakage of the lowering transformers has been added to the load.

have a load current expressed in rectangular coordinates with the load voltage as a temporary vector of reference. To this we add algebraically a phase modifier current (loss + j or leading) and to this we add the transformer leakage (loss — j or lagging). In other words, these three components of current at the receiving end of the line add up algebraically upon a transformers and phase modifiers flowing over the line.

For the purpose of determining the magnitude of errors in the calculated results corresponding to simplified methods of calculation where transformers are required at both ends of the line, the calculations shown in Table V were made. Five methods of calculations were made for each of four sizes of cable. A con-

TABLE W—PERCENTAGE ERRORS IN RESULTS, AS DETERMINED BY VARIOUS METHODS OF CALCULATION.

These methods do not take complete account of the effects of the transformers in the circuit

Method	At Generator Percent Error: E_{gen}	I_{gen}	PF_{gen}	At Sending End Percent Error: E_s	I_s	PF_s	Line Loss Percent Error	Transformer Account
A	0	0	0	0	0	0	0	Complete method—Assumed for comparison as resulting in 100 percent values.
B	...	...	...	−3.7	+3.9	−0.42	+0.37	Leak of lowering transformers ignored. Impedance of lowering transformers assumed as line impedance.
C	−1.8	+2.8	−2.35	...	...		+0.17	Leaks of raising and lowering transformers ignored. Impedance of raising and lowering transformer assumed as line impedance.
D	...	...		−1.6	+0.4	+0.55	+0.05	Same as *B* except that the transformer leak has been added to the load.
E	+0.5	−0.7	−1.62	...	...	...	−0.12	Same as *C* except that the transformer leak has been added to the load.

common vector of reference, thus making it very easy to obtain the resulting load at the receiving end of the line.

The transformers at the sending end of the line have been considered as receiving their magnetizing stant load, load voltage and condenser capacity were assumed for all calculations and the results of these calculations are tabulated in Table W. Thus method *B* which does not take any account of the lowering transformer magnetizing current and assumes the transformer im-

pedance as line impedance, gives the sending end voltage too low by 3.7 percent and the current too high by 3.9 percent.

Table X contains approximate data upon transformers of various capacities 25 and 60 cycles. Since such data will vary greatly for different voltages it must be considered as very approximate but may be found useful in the absence of specific data for the problem at hand.

Fig. 67 shows complete current and voltage diagrams for both short and long lines. The diagram illustrating short lines is based upon the current having the same value and direction at all points of the circuit. On this basis the IR drops of the line and of the raising and lowering transformers will be in the same direction. Likewise their individual IX drops will also be in the same direction. It is evident, therefore, that, for short lines where the capacitance is neglible, the transformer impedance may be added directly to the line impedance, provided the electrical characteristics on the high-tension side of the transformers are not required.

As the line becomes longer, the current changes in both amount and direction from point to point, as a result of the superimposed distributed charging current of the line. The result of this is that the impedance triangles of the line and of lowering and raising transformers change in both size and relative position; so that their individual impedances can no longer be added together and considered as all line impedance, without accepting an error in the results thus obtained. The complete diagram for long lines shown by Fig. 67 will be considered later.

TRANSFORMER IMPEDANCE TO NEUTRAL*

Transformer constants are referred to the high voltage circuit in order to combine properly with the linear constants of the line. Although all calculations are made in terms of the high-voltage circuit the results may, if desired, be converted to terms of the low voltage circuit, by applying the ratio of transformation.

The transformer impedance to neutral is one-third the equivalent single-phase value. The reason for this is that the I^2R and I^2X for one phase is identical whether to neutral or between phases. Since the current between phases is equal to the current to neutral divided by $\sqrt{3}$, the square of the phase current would be one-third the square of the current to neutral; therefore, R and X to neutral will be one-third the phase values. Another way of looking at this is that the resistance and reactance ohms vary with the square of the voltage, and since the phase voltage is $\sqrt{3}$ times the voltage to neutral, the phase resistance and phase reactance would be three times that to neutral. In calculating the impedance to neutral, the results will be the same whether star or delta connection is used.

TABLE X—APPROXIMATION OF RESISTANCE AND REACTANCE VOLTS, OF IRON AND COPPER LOSSES AND OF MAGNETIZING CURRENT FOR TRANSFORMERS OF VARIOUS CAPACITIES

Capacity of Transformer	60 Cycles per Second					25 Cycles per Second				
	Percent	Percent	Percent Loss		Percent Magnetizing	Percent	Percent	Percent Loss		Percent Magnetizing
KV-A	*Resistance	*Reactance	Iron	Copper	Current	Resistance	Reactance	Iron	Copper	Current
200	1.5	5.5	1.4	1.5	10	2.6	4.0	1.1	2.6	10
300	1.3	5.6	1.3	1.3	9	2.15	4.0	1.0	2.15	10
500	1.2	6.0	1.2	1.2	8	1.85	4.1	1.0	1.85	9
750	1.1	6.3	1.0	1.1	8	1.65	4.2	0.9	1.65	9
1000	1.1	6.5	0.9	1.1	7	1.55	6.0	0.8	1.55	8
1500	0.9	7.0	0.8	0.9	6	1.4	6.2	0.8	1.4	8
2000	0.8	7.0	0.7	0.8	6	1.3	6.4	0.7	1.3	8
3000	0.75	7.0	0.7	0.75	6	1.2	6.8	0.6	1.2	7
5000	0.65	7.0	0.6	0.65	6	1.1	7.2	0.5	1.1	7
7500	0.6	8.0	0.6	0.6	5	1.0	7.8	0.5	1.0	7
10000	0.6	8.0	0.5	0.6	5	1.0	8.0	0.5	1.0	6
15000	0.55	8.5	0.5	0.55	5	0.95	8.0	0.6	0.95	6
25000	0.5	9.0	0.6	0.5	5	0.9	8.0	0.6	0.9	6
35000	0.5	9.5	0.6	0.5	5	0.9	9.0	0.6	0.9	6
50000	0.5	10.0	0.6	0.5	5	0.9	9.0	0.6	0.9	6

*The actual ohms resistance and ohms reactance will vary as the square of the voltage. The values in above table must be considered as only roughly approximate. They will vary materially with transformers wound for different voltages

Even if the transformers at both ends of the transmission line are duplicates their impedance will not be the same if operated on different taps of the windings to accommodate different voltages. In such cases, their impedances will vary as the square of the voltages. For instance, if they are operated at 220 and 230 kv at the receiving and sending end respectively, then their impedances will have the relation of $\frac{220^2}{230^2} = 0.915$. In other words, if the resistance and reactance of the receiving end transformers is 3.185 and 39.82 ohms respectively, the sending end transformers will have resistances and reactances of 3.481 and 43.52 ohms respectively; provided transformer taps corresponding to this higher voltage are used.

The impedance in ohms of an 18 000 kv-a, three-phase, or of three 6000 kv-a single-phase transformers, connected in a bank, may be determined as fol-

*The writer desires to express his appreciation of helpful assistance and useful data on transformer characteristics received from Mr. J. F. Peters.

lows. Assume that they are operated at 104 000 volts between conductors (60 046 to neutral) and that the resistance voltage is 1.04 percent and reactance voltage is 4.80 percent.

The single-phase values are:—

$$\frac{6\,000\,000}{104\,000} = 57.7 \text{ amperes}$$

$$R_t = \frac{104\,000 \times 0.0104}{57.7} = 18.75 \text{ ohms resistance}$$

$$X_t = \frac{104\,000 \times 0.048}{57.7} = 86.52 \text{ ohms reactance}$$

The values to neutral are, as stated above, one-third of the above; but, for the sake of uniformity in determining values to neutral, should preferably be determined as follows:—

$$\frac{6\,000\,000}{60\,046} = 99.92 \text{ amperes to neutral}$$

$$R_{tn} = \frac{60\,046 \times 0.0104}{99.92} = 6.25 \text{ ohms resistance to neutral}$$

$$X_{tn} = \frac{60\,046 \times 0.0480}{99.92} = 28.84 \text{ ohms reactance to neutral}$$

If two or more banks operate in parallel, the resulting impedance Z_r can be obtained by taking the reciprocal of the sum of the reciprocals of the individual impedance. Thus:—

$$Z_r = \frac{Z_1\,Z_2}{Z_1 + Z_2}$$

In the above example $Z_t = \sqrt{1.04^2 + 4.8^2} = 4.91$ percent.

To parallel two banks containing transformers duplicates of the above, we get, by the above rule, the following resultant impedance:—

$$Z_r = \frac{4.91 \times 4.91}{4.91 + 4.91} = 2.45 \text{ percent}$$

Which is just half the impedance of a single bank, as is evident without applying the rule.

Where two or more banks are to be operated in parallel consisting of transformers not duplicates, then the above rule must be applied to determine the resultant impedance. If the impedances are expressed in percent, as is usual, then they must be both referred to the same kv-a base. For instance, if a 6000 kv-a and a 3000 kv-a transformer each have a resistance of 1.04 percent and a reactance of 4.8 percent, their impedance is 4.91 percent. Before combining the impedances, that of the 3000 kv-a unit should be put in terms of the 6000 kv-a, and the resultant would be:—

$$Z_r = \frac{4.91 \times 9.82}{4.91 + 9.82} = 3.27 \text{ percent at 6000 kva.}$$
$$= 0.69 \text{ percent resistance volts at 6000 kva.}$$
$$= 3.19 \text{ percent reactance volts at 6000 kva.}$$

If the impedance triangles of the two banks to be paralleled are considerably different (that is their ratio of resistance to reactance) it will be necessary to express the impedances in complex form. We have assumed above that the triangles are proportional, otherwise they would not divide the load evenly at all power-factors. Solving the preceding problem for the resultant impedance by complex notation, we get:

$$Z_r = \frac{(1.04 + j4.8) \times (2.08 + j9.6)}{(1.04 + j4.8) + (2.08 + j9.6)}$$
$$= \frac{-43.917 + j19.968}{3.12 + j14.4}$$
$$= \frac{48.25 \diagdown 155^\circ 32' 58''}{14.734 \angle 77^\circ 46' 29''}$$
$$= 3.27 \angle 77^\circ 46' 29'' \text{ ohms}$$
$$= 0.69 + j\,3.19 \text{ ohms}$$

Which checks with the results determined above on the percentage basis.

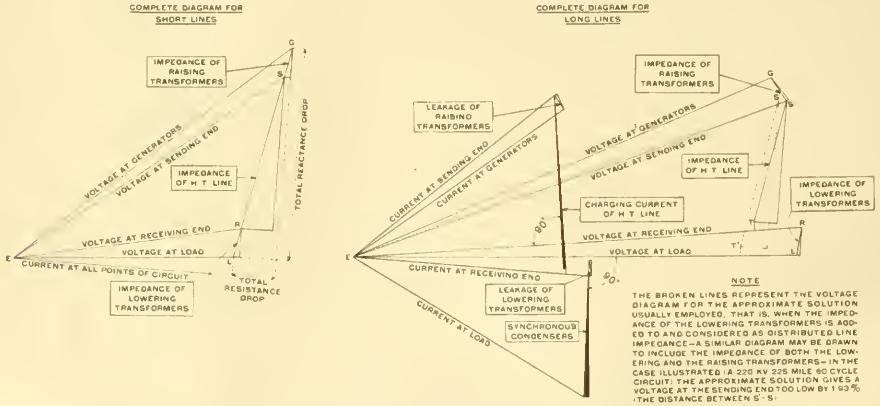
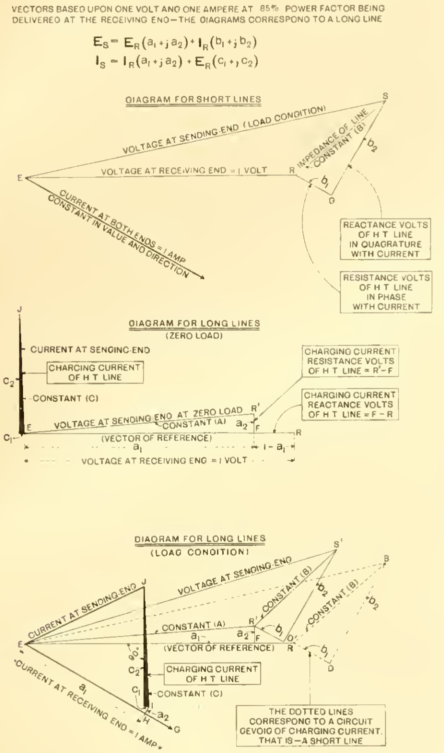


FIG. 67—VECTOR DIAGRAMS FOR SHORT AND LONG LINES

THE AUXILIARY CONSTANTS

The graphical construction for short lines represented typically by the Mershon Chart is so generally known and understood that a similar construction modified to take into accurate account the distribution effect of long lines will readily be followed. Both the short and the long line diagrams are reproduced in Fig. 68. From these diagrams it will be seen how the three auxiliary constants correct or modify the short line diagram adapting it to long line problems. The two mathematical and three graphical methods of obtaining the auxiliary constants are indicated at the

bottom of this figure. Since the auxiliary constants are functions of the physical properties of the circuit and of the frequency only, they are entirely independent of the voltage or the current. Having determined



HOW THE AUXILIARY CONSTANTS MAY BE OBTAINED

$$(A) = (a_1 + j a_2) = \left[1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \frac{Y^3Z^3}{720} + \frac{Y^4Z^4}{40.320} + \text{ETC}\right] \text{ (BY CONVERGENT SERIES—SEE CHART XI)}$$
$$= \cosh\theta \text{ (BY REAL HYPERBOLIC FUNCTIONS—SEE CHART XVI)}$$
$$= \frac{\sinh\theta/\theta}{\tanh\theta/\theta} \text{ (GRAPHICAL—SEE KENNELLY CORRECTING FACTOR CHARTS XVIII XIX XX-XXI)}$$
$$= \cosh\theta \text{ (GRAPHICAL—SEE KENNELLY'S CHART ATLAS, HARVARD PRESS)}$$
$$= \cosh\theta \text{ (ALL GRAPHICAL FROM WILKINSON'S CHART "A"—SEE CHART V)}$$

$$(B) = (b_1 + j b_2) = Z\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5.040} + \frac{Y^4Z^4}{362.880} + \text{ETC}\right] \text{ (BY CONVERGENT SERIES—SEE CHART XI)}$$
$$= \sqrt{\frac{Z}{Y}}\sinh\theta \text{ (BY REAL HYPERBOLIC FUNCTIONS—SEE CHART XVI)}$$
$$= Z\frac{\sinh\theta}{\theta} \text{ (GRAPHICAL—SEE KENNELLY'S CORRECTING FACTOR CHARTS XVIII-XIX)}$$
$$= \sqrt{\frac{Z}{Y}}\sinh\theta \text{ (GRAPHICAL—SEE KENNELLY'S CHART ATLAS, HARVARD PRESS)}$$
$$= \sqrt{\frac{Z}{Y}}\sinh\theta \text{ (ALL GRAPHICAL FROM WILKINSON'S CHART "B"—SEE CHART VI)}$$

$$(C) = (c_1 + j c_2) = Y\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5.040} + \frac{Y^4Z^4}{362.880} + \text{ETC.}\right] \text{ (BY CONVERGENT SERIES—SEE CHART XI)}$$
$$= \frac{1}{\sqrt{\frac{Z}{Y}}}\sinh\theta \text{ (BY REAL HYPERBOLIC FUNCTIONS—SEE CHART XVI)}$$
$$= Y\frac{\sinh\theta}{\theta} \text{ (GRAPHICAL—SEE KENNELLY'S CORRECTING FACTOR CHARTS XVIII-XIX)}$$
$$= \frac{1}{\sqrt{\frac{Z}{Y}}}\sinh\theta \text{ (GRAPHICAL—SEE KENNELLY'S CHART ATLAS, HARVARD PRESS)}$$
$$= \frac{1}{\sqrt{\frac{Z}{Y}}}\sinh\theta \text{ (ALL GRAPHICAL FROM WILKINSON'S CHART "C"—SEE CHART VII)}$$

WHERE $\theta = \sqrt{ZY}$

FIG. 68—HOW THE AUXILIARY CONSTANTS MODIFY SHORT LINE DIAGRAMS ADAPTING THEM TO LONG LINE PROBLEMS

by any of the five methods referred to, the value for the auxiliary constants corresponding to a given circuit, the remainder of the solution for any receiving end current or voltage is readily performed graphically.

Constants a_1 and a_2—If the line is short electrically the charging current, and consequently its effect upon the voltage regulation is small. In such a case constant a_1 would be unity and constant a_2 would be zero, and the line impedance triangle would be attached to the end of the vector ER representing the receiving end voltage, since this vector also represents the sending end voltage at zero load.

If, however, the circuit contains appreciable capacitance, the e.m.f. of self-induction resulting from the charging current will result in a lower voltage at zero load at the sending end than at the receiving end of the line. Obviously, the load impedance triangle must be attached to the end of the vector representing the voltage at the sending end of the circuit at zero load. This is the vector ER' of the long line diagrams of Fig. 68. In such a circuit the effect of the charging current is sufficiently great to cause the shifting of the point R for a short line to the position R' for the long line. The constants a_1 and a_2 therefore, determine the length and position of the vector representing the sending end voltage at zero load. Actually the constant a_2 represents the volts resistance drop due to the charging current for each volt at the receiving end of the circuit. That is, the line FR' equals approximately one-half the charging current times the resistance R, taking into account, of course, the distributed nature of the circuit. For a short line, it would be sufficiently accurate to assume that the total charging current flows through one-half the resistance of the circuit. To make this clear, it will be shown later that, for a 220 kv problem, the resistance per conductor is $R = 34.65$ ohms and the auxiliary constant $C_2 = 0.001211$ mho. Thus, this line will take 0.001211 ampere charging current, at zero load, for each volt maintained at the receiving end, and since $FR' =$ approximately $I_{cc} \times \frac{R}{2}$ we have FR' or $a_2 = 0.001211 \times \frac{34.65}{2} = 0.020980$. The exact value of a_2 as calculated by hyperbolic functions, taking into account the distributed nature of the circuit is 0.020234. Since the charging current is in leading quadrature with the voltage ER, the resistance drop FR' due to the charging current is also at right angles to ER.

The length of the line FR or (one-a_1), represents the voltage consmed by the charging current flowing through the inductance of the circuit. This may also be expressed with small error if the circuit is not of great electrical length as $I_{cc} \times \frac{X}{2}$. The reactance per conductor for the 220 kv problem is 178.2 ohms. Therefore, $FR = 0.001211 \times \frac{178.2}{2} = 0.107900$ and $a_1 = 1 - 0.107900 = 0.892100$. The exact value of a_1 as calculated rigorously, is 0.893955.

Constants b_1 and b_2—These constants represent respectively the resistance and the reactance in ohms,

as modified by the distributed nature of the circuit. The values for these constants, multiplied by the current in amperes at the receiving end of the circuit, give the IR and IX volts drop consumed respectively by the resistance and the reactance of the circuit. To illustrate this, the values of R and X for the 220 kv problem are 34.65 ohms and 178.2 ohms per conductor. The distributed effect of the circuit modifies these linear values of R and X so that their effective values are $b_1 = 32.198$ and $b_2 = 172.094$ ohms. The line impedance triangle, as modified to take into exact account the distributed nature of the circuit, is therefore smaller than it would be if the circuit were without capacitance.

Constants c_1 and c_2—These constants represent respectively the conductance and susceptance in mhos as modified by the distributed nature of the circuit. The values for these constants, multiplied by the volts at the receiving end of the circuit, give the current consumed respectively by the conductance and the susceptance of the circuit. To illustrate, the linear value of c_2 for the 220 kv problem is 0.001211 mho. The distribution effect of the circuit modifies this linear value so that its effective value $c_2 = 0.001168$. The value of c_1 is so small that its effect is negligible for all except for long circuits. An exception to this statement would be that if the line loss is very small compared to the amount of power transmitted the percent error in the value of line loss may be considerably increased if the effect of c_1 is not included in the solution. If c_1 is ignored, c_2 will represent the charging current at zero load per volt at the receiving end. Thus c_2 multiplied by the receiving end voltage, gives the charging current at zero load for the circuit. For the 220 kv problem $c_2 = 0.001168$ and this multiplied by 127 020, the receiving end voltage to neutral, gives 148.36 amperes charging current per conductor.

Referring to the formulas at the top of Fig. 68, $E_r\ (a_1 + j\ a_2)$ is that part of E_s which would have to be impressed at the sending end if $I_r = 0$, or the line was freed at the receiving end with E_r steadily maintained there. It may be called "free" component of E_s*. Again $I_r\ (b_1 + j\ b_2)$ is that other part of E_s which would have to be impressed at the sending end, if $E_r = 0$, or the line was short-circuited at the receiving end, with I_r steadily maintained there. It may be called the "short" component of E_s.

Similarly, the term $I_r\ (a_1 + j\ a_2)$ is the component of I_s necessary to maintain I_r at the receiving end without any voltage there ($E_r = 0$); while $E_r\ (c_1 + j\ c_2)$ is the component of I_s necessary to maintain E_r at the receiving end without any current there ($I_r = 0$). The reason that c_1 is likely to be negative in ordinary power lines is because the complex hyperbolic angle of any good power transmission line has a large slope, being usually near 88 degrees. The sinh of such an angle, within the range of line lengths and sizes of θ ordinarily present, is also near 90 degrees in slope. The surge impedance $Z_o = \sqrt{\frac{Z}{Y}}$ of such a line is not far from being reactanceless; but it usually develops a small negative or condensive slope. This means that the surge admittance $Y_o = \frac{I}{Z_o}$ usually develops a small positive slope. Consequently, C or the product $E_r\ (c_1 + j\ c_2)$ usually slightly exceeds 90 degrees in slope; or c_1 becomes a small negative rectilinear component.

*See paper by Houston and Kennelly on "Resonance in A. C. Lines" in Trans. A. I. E. E. April, 1895

Methods of Magnetic Testing (Concl.)

T. SPOONER

HIGH INDUCTIONS

To obtain normal-induction and hysteresis data at very high inductions requires special methods, since the ordinary commercial permeameters have, in general, an upper limit of magnetizing force of 300 to 400 gilberts per centimeter, though for very short intervals some of them may be operated somewhat higher. The teeth of rotating machines sometimes require magnetizing forces of thousands of gilberts per centimeter to produce the required induction. Also for certain scientific work it is often desirable to obtain data on material at high inductions.

Isthmus Method—The best known method for obtaining high induction data is the isthmus method in one of its various modifications[21]. If a powerful electromagnet with conical pole pieces, Fig. 21, is arranged to take a bobbin shape sample b, with a narrow cylindrical neck a, the neck may be uniformly magnetized to a very high induction if the pole pieces and bobbin are suitably shaped. If two concentric coils with the same number of turns, but one with an appreciably larger diameter than the other, are wound on the central cylinder, we can measure B and H. B is measured by connecting the inside coil to a ballistic galvanometer and removing, or better reversing the bobbin in the pole pieces. H is measured by a similar operation with the two concentric coils connected in opposition to the ballistic galvanometer. By using a sufficiently strong electromagnet, magnetizing forces of many thousand gilberts per centimeter may be obtained. If a ballistic galvanometer with a sufficiently long period is available, it is possible to obtain satisfactory resul‘s

by reversing the magnetizing current of the electromagnet.[22].

Modified Isthmus Method—Campbell and Dye[23], and more recently the U. S. Bureau of Standards[24] have used a modification of the isthmus method for determining inductions for magnetizing forces up to a few thousand gilberts per centimeter. The Bureau of Standards method is represented by Fig. 22. A powerful electromagnet was drilled as shown to take a cylindrical sample 0.6 cm. indiameter. Outside of this sample are three concentric helical coils of fine wire, each having the same number of turns. B is measured by connecting the inside coil to a ballistic galvanometer and reversing the magnetizing current. H is determined by connecting the two inside coils in series opposing to the ballistic galvanometer, noting the deflection when the magnetizing force is reversed and then doing the same with the outside pair. The gradient of the magnetizing force can then be determined and extrapolated to the surface of the sample. The hysteresis data may be obtained by a procedure similar to that used for the Fahy Simplex permeameter.

It was found by the Bureau of Standards to be rather difficult to obtain correct coercive-force data due to the magnetic viscosity and retentivity of the yokes and possibly to other causes. By a modification of the usual procedure, however, this difficulty was overcome. Referring to Fig. 2, if the induction is reduced apparently to zero, the actual induction is probably some other value, due to the above-mentioned effects. The procedure adopted is to bring B approximately to zero by introducing resistance into the magnetizing circuit and reversing the magnetizing current so that $\Delta B = B_m$ apparently. Then the induction is rapidly increased to $-B_m$ and back to B_0. In general, the galvanometer will indicate a residual deflection. By repeating the procedure, varying the added resistance in the magnetizing circuit, this residual deflection can be reduced to zero. Then by repeating the procedure with the H coils connected to the galvanometer the resulting deflection will be $2H_c$. By comparison with tests on the same samples with other types of apparatus, this procedure was found to give correct results. The Bureau of Standards method has the advantage over the original Ewing isthmus method, in that it uses simple cylindrical rods instead of the complicated bobbin samples. For magnetizing forces up to several thousand gilberts per centimeter it should be quite satisfactory.

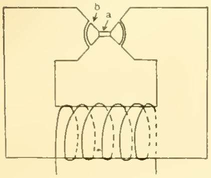


FIG. 21
ELECTROMAGNET WITH CONICAL POLE PIECES AND BOBBIN USED IN THE ISTHMUS METHOD

Optical Methods—By the use of the optical method it is possible to obtain high induction data[11]. I (intensity of magnetization) is measured by noting the angle of rotation of the beam of polarized light reflected from the magnetized surface and B is measured according to the method used by DuBois, by noting the angle of rotation produced by the introduction of a glass plate just in front of the magnetized surface. The angular rotation produced by the glass is proportional to the lines of flux. If the glass has been standardized B is known. Then the magnetizing force,—

$$H = B - 4\pi I \quad \ldots \ldots \ldots (4)$$

This optical method is suitable only for high inductions and is not as simple or direct as the isthmus method. For a discussion of other methods see Bureau of Standards, Scientific Paper No. 361[24].

Extrapolation Methods—Kennelley[25] some years ago and others[26] more recently have shown that it is possible to extrapolate normal induction data to high values with a considerable degree of accuracy. Assume a set of normal induction data and calculate the values of the reluctivity ρ_0 corresponding to definite values of H, where,— $\rho_0 = \frac{H}{B_0}$

B_0 is the ferric induction as explained previously where

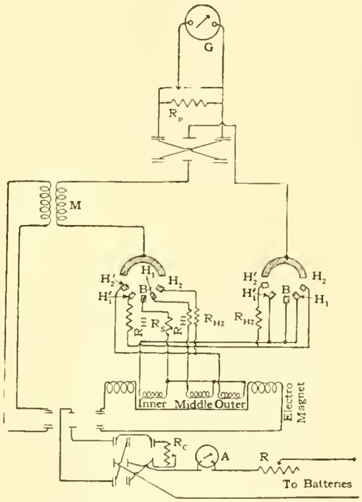


FIG. 22—MODIFIED ISTHMUS METHOD AS USED BY THE U. S. BUREAU OF STANDARDS

$B_0 = B - H$. Now if we plot ρ_0 against H, Fig. 23, we obtain the curve *cdc* of approximately the shape indicated. This curve is, in general, approximately a straight line and may be expressed by the equation— $\rho_0 = a + \sigma H$ where a is the intercept on the ρ_0 axis, and σ is the straight portion of the curve. The straight portion of the curve may begin at 50 gilberts per centimeter or more often not until we go as high as 200. For most commercial materials a satisfactory extrapolation may be made from points at, say 200 and 400 gilberts per centimeter. It is not safe to use points below 200 unless the curves have been actually plotted and found to be straight below 200.

Recently Sanford and Cheney[27] have shown that an entirely similar procedure may be used for extrapolating B_r and H_c, where,—

$$H_m \div B_r = a_1 + b_1 H_m \quad \ldots (7)$$
$$H_m \div H_c = a_2 + b_2 H_m \quad \ldots (8)$$

where H_m = the maximum magnetizing, forec, B_r = the residual induction, H_c = the coercive force, a_1 and a_2 = the intercepts on the axis of ordinates, b_1 and b_2 = the slopes of the lines. The reciprocal of σ gives the saturation value for B_o. The reciprocal of b_1 gives the saturation value of B_r and the reciprocal of b_2 gives the saturation for H_c. Thus we see that B_r and H_c approach a saturation valuation as does B_o when the magnetizing force is increased. This fact was demonstrated with the Bureau of Standards high induction apparatus previously described.

Accurate extrapolations can not be made by this method on a few specific materials, such as the new Honda steels, unless we go to magnetizing forces of many hundreds gilberts per centimeter. With one of the Honda steels there is a bend in the reluctivity curve at 1500 gilberts per centimeter. Therefore, in order to determine the saturation value we must obtain test data above this point. A bend in the reluctivity curve is the result of the presence of two or more constituents in the material having different magnetic characteristics.

HYSTERESIS LOSS DETERMINATIONS

Hysteresis losses, aside from the alternating-current methods which will be discussed later, may be determined in a number of ways as follows:

1.—Most of the previously described permeameters may be used for obtaining hysteresis loops with more or less accuracy. From the area of these loops hysteresis losses may be calculated.

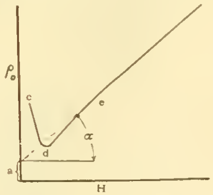


FIG. 23—EXTRAPOLATION CURVE

2. Rice and McCollum[28] some years ago described a method of obtaining hysteresis losses directly by means of a ballistic hysteresis meter. If a dynamometer wattmeter is arranged with its moving element suspended like a galvanometer we have the essentials of a ballistic hysteresis meter. If we have, for instance, a ring sample wound with a magnetizing and secondary winding and connect the magnetizing winding in series with the stationary coils of the hysteresis meter, and connect the sample secondary to the moving coil of the meter and then reverse the magnetizing current, the ballistic throw of the moving coil will be proportional to the hysteresis loss in the sample.

3.—Various types of hysteresis meters have been developed, of which the Ewing[29] is a typical form. The test sample consists of a rectangular specimen 5/8 by 3 inches, which is revolved between the poles of a permanent magnet, the latter being mounted on pivots and provided with a pointer. The hysteresis loss in the sample produces a deflection of the magnet, the deflection being proportional to the hysteresis loss, practically independent of the speed of rotation, provided the speed is sufficiently low so that no appreciable eddy currents are produced. The apparatus is calibrated by means of standard samples of known quality.

The Blondel apparatus is similar in operation to the Ewing except that in this case the magnet is rotated and the deflection of the sample is noted.

In the Holden type of apparatus a ring sample is used with a revolving magnet. The sample is controlled by springs and is brought back to its initial position by means of a torsion head.

The permeameter methods of obtaining hysteresis losses are accurate if the permeameters are accurate, as discussed above. According to the authors the ballistic hysteresis method when used with ring samples is accurate, provided proper precautions are used to keep the eddy current losses down to a minimum. The hysteresis meters of the Ewing-Blondel-Holden types are now practically obsolete, although they have been used considerably in the past. They may have some applications when a comparison is required between small samples of similar material. In general, however, hysteresis loss is of interest only for sheet material. In order to obtain a good check on sheets it is desirable to use a considerable quantity of material as the quality from one portion of the sheet to another varies appreciably. Moreover, unless the samples are annealed they must be fairly large to eliminate the effects of shearing or punching. Also changes of permeability of the sample will make the value of the induction uncertain in the Ewing-Blondel and Holden types of hysteresis meters. Due to these limitations the alternating-current methods of obtaining losses on sheets have superseded the other methods for most commercial work.

CALCULATIONS OF HYSTERESIS LOSSES FROM LOOPS

If a hysteresis loop is plotted with B expressed in gausses and H in gilberts per centimeter or gausses, the hysteresis loss is obtained as follows:—

$$W_h = \frac{K A}{4\pi} \quad \ldots (9)$$

Where W_h = the hysteresis loss in ergs per cubic centimeter per circle, $K = B \times H$ for unit area. A = area of loop in any convenient units. If A is measured in square inches and B equals 1 kilogauss per inch and H equals 2 gilberts per centimeter for one inch, then K equals 2000. A is ordinarily measured by means of a planimeter. When a planimeter is not available or greater speed is required with less accuracy an approximate method may be used for obtaining W_h. According to circular No. 17 of the Bureau of Standards,

$$K A = 4 H_c \times B_m \quad \ldots (10)$$

to an accuracy of plus or minus 15 percent.

A more accurate formula is the following for hysteresis loops having a maximum B of 10 kilogausses[17].

$$W_h = \frac{2 (H_s'' - H_s')}{2 H_c + (H_s'' - H_s')} \times \frac{H_c \times 10^4}{\pi} \quad \ldots (11)$$

where H_s' and H_s'' are the two values of H, corres-

ponding to the two positive or negative values of B at 8 kilogausses. H_8'' is the numerically larger value and H_8' is subtracted algebraically. The accuracy is usually better than plus or minus 5 percent.

ALTERNATING-CURRENT METHODS

If a sample of magnetic material is subjected to an alternating flux we have the following losses.

1—Hysteresis loss
2—Eddy-current loss
3—Apparent loss

For most commercial purposes it is sufficient to test for total core loss under standard conditions without separating the hysteresis and eddy-current losses. However, when it becomes necessary there are several methods available for making this separation. It is customary in this country[17] to test electrical sheet at a maximum induction of 10 kilogausses and a frequency of 60 cycles, the corresponding core loss being denoted by the symbol $W_{10}/_{60}$. In Europe the material is usually tested at inductions of 10 and 15 kilogausses at a frequency of 50 cycles.

Apparent loss is not as well known or generally used a quantity as true loss, but it is useful in transformer design for calculating the exciting current. It is equal to the product of the volts and amperes for a given induction and frequency for a given weight of core material surrounded by a magnetizing winding.

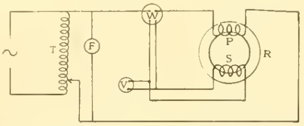


FIG. 24—CONNECTIONS FOR CORE LOSS TEST OF LAMINATED STEEL RING SAMPLE

In the finished apparatus the apparent loss is a function not only of the intrinsic quality of the material, but the number and size of air-gaps in the completed apparatus. Therefore, apparent loss factors have to be applied with caution.

Hysteresis and eddy-current losses may be expressed by the following well-known formula,

$$W = K_1 f B^x + K_2 f^2 t^2 B^y \qquad (12)$$

where K_1 and K_2 are constants, f is the frequency, and t is the thickness of laminations. For moderate induction $X = 1.6$ approximately (Steinmetz exponent) and $y = 2$ approximately. For commercial sheet steel the 1.6 law for hysteresis will hold approximately for ranges of induction from 1 to 16 kilogausses. Outside of this range the law fails to express the facts with any degree of acuracy. K_2 is approximately inversely proportional to the resistivity of the material. For a more detailed discussion of the hysteresis law see Bureau of Standards Circular No. 17.

TYPES OF TEST

Alternating-current methods of obtaining core loss may be classified as follows.

1—Ring test.
2—Epstein
 a—Standard. b—Differential. c—Substitution.
3—Lloyd.
4—Robinson.
5—Three phase ring (high induction).
6—High frequency.

1—If a ring sample of laminated steel be wound with a primary and secondary winding, the core loss may be tested as shown by Fig. 24. The primary is connected to a source of alternating current through a wattmeter to an autotransformer T. The secondary is connected to the shunt circuit of the wattmeter with a voltmeter V. A frequency meter F is used to indicate the frequency of the supply circuit. For these connections V is proportional to the maximum induction in the sample.

$$B = \frac{E \times l \times D \times 10^8}{4 \times f \times N \times n \times W} \qquad (13)$$

Where E is the r.m.s. volts, l is the mean circumference of the ring in cms., D is the density, f is the form-factor, N is the number of secondary turns, n is the frequency in cycles per second, and W is the weight in grams. The wattmeter gives the core loss plus the instrument losses in the voltmeter and the shunt circuit of the wattmeter. The use of the secondary winding is desirable because it eliminates any errors due to IR drop or I^2R losses in the primary.

The ring test is subject to certain errors[30]. For reasonably accurate results it is necessary that the induced voltage have practically a sine wave form-factor or at least that the form-factor be known. For a

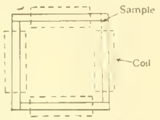


FIG. 25—ARRANGEMENT OF EPSTEIN SAMPLES FOR CORE LOSS TEST

discussion of the effect of form-factor on iron losses see *Bureau of Standards Scientific Papers* 88[31] and 106[32]. The form-factor may be determined by using a synchronous commutator or suppressor[33]. The ring sample is used only in special cases as it is too difficult to wind each sample and more material is wasted than for the Epstein test.

2-a—The Epstein method is the standard method adopted by the American Society for Testing Materials[17], and is very widely used in this country and abroad. The connections are the same as for the ring test (Fig. 24) the only difference being that the sample now consists of four equal bundles or strips of sheet material arranged in a hollow square as shown in Fig. 25. The strips are 50 by 3 cm. and weigh 10 kilograms. Each bundle is slipped into a solenoid as indicated by the dotted lines. The solenoids each have two layers of wire. The outside layer is used as the primary and the inside as a secondary. The four primary and secondary coils are connected in series. Since there is often a difference of 10 or 15 percent between the losses of sheet material sheared parallel and at right angles to the direction of the grain[34], it is usually specified that one half of the material shall be sheared one way and one half the other. For a de-

scription of the standard core loss apparatus as used by the Research Department, see a previous paper by the author[35].

The Epstein apparatus is supplied from a generator in series with which is connected a harmonic booster giving a third harmonic. By varying the amplitude of the third harmonic the form-factor of the induced voltage of the Epstein apparatus may be kept at 1.11 as indicated by means of a direct-current voltmeter and suppressor together with an alternating-current voltmeter connected to the secondary of the Epstein apparatus. This is an expensive and complicated method and should be used only where a primary standard apparatus is required for standardization or special work. For routine acceptance tests a sine-wave generator may be used if obtainable. If not, satisfactory results may be obtained from the 60 cycle commercial supply by using some compensation or differential arrangement.

2-b—Siemens and Halske developed an arrangement using a standard sample and a differential wattmeter, one element of which was connected to the standard Epstein apparatus and the other to an Epstein apparatus containing the unknown sample. By varying the resistance in the potential circuits of the wattmeter the readings could be brought to zero and the ratio of these resistances was the ratio of the losses in the two samples. If the standard and unknown samples are of similar material it is obvious that commercial changes of voltage or frequency will not alter the results appreciably.

2-c—In order to avoid the necessity of using a special differential wattmeter a substitution method may be used[35]. If an Epstein apparatus containing a standard sample is connected to an alternating-current supply in the usual way with a voltmeter and wattmeter, and the voltmeter is adjusted until the wattmeter reads the known loss in the standard sample, and the apparatus is then connected to another Epstein apparatus containing an unknown sample, with the voltmeter adjusted to its previous reading, the wattmeter will read directly the loss in the unknown sample, provided no considerable changes in the form-factor or frequency have occurred between the two readings. Moreover, the instruments may be considerably out of calibration without appreciably effecting the accuracy of the results.

While the Epstein apparatus is the standard, it is subject to slight errors due to the type of magnetic circuit. The shape of the circuit and the butt joints tend to produce leakage and non-uniform flux, thus introducing errors of possibly two or three percent in the losses. Also the effect of shearing of the samples produces quite appreciable increased losses unless the material is annealed before testing.

3—M. G. Lloyd[36] undertook to overcome these disadvantages by a modified Epstein apparatus. The samples weigh only two kilograms and are 10 by 2 inches and are placed on edge with special formed corner pieces of known magnetic quality. This arrangement keeps the flux more nearly uniform throughout the sample and reduces the shearing effect by using a wider sample.

The Epstein and the Lloyd apparatus in general require a considerable quantity of the material. A five kilogram Epstein sample of silicon steel will cost, including shearing, perhaps a dollar or more. When hundreds of samples per month are tested, this may be an appreciable item.

4—In order to reduce the weight of the sample required Mr. L. T. Robinson some years ago devised an apparatus for determining the hysteresis loss by a low frequency method[37], which required a sample weighing only about one pound. The sample consisted of a single bundle of strips 10 by 0.5 inches, placed in a magnetic solenoid supplied with current at about 10 cycles. The losses were measured by a sensitive wattmeter and corrections made for the small eddy-current losses. The flux was of course not uniform but a correction factor was applied to take care of this factor. The apparatus is said to be accurate to plus or minus five percent, which is not quite as good as the Epstein.

5—If an attempt is made to use any of these methods to obtain results at high inductions it is difficult to obtain satisfactory data, due chiefly to the fact that the large exciting current with its high harmonics greatly distorts the induced voltage wave due to the inductance and resistance in the primary circuit. As a consequence the form-factor becomes quite different from the desired value. Nicholson[38] attempted to overcome this difficulty partly at least by using three identical ring samples with primary, secondary and tertiary windings. The primary windings were connected in Y to a three-phase source through wattmeter current coils. The secondary windings were also connected in Y to the shunt circuits of the wattmeters. The tertiary windings were connected in Δ to a generator giving a third harmonic current. Since the third harmonic is chiefly responsible for the distortions of the induced voltage, these distortions could be greatly reduced by supplying the necessary third harmonic from a separate source. By this means it is possible to obtain satisfactory iron loss results up to considerably over 20 000 gausses.

6—The above mentioned methods have dealt with moderate frequency tests. In these days of radio development it is sometimes desirable to obtain iron-loss results at radio frequencies. It is undoubtedly possible to obtain satisfactory results by the use of an electro-static wattmeter and possibly by some bridge method. A very satisfactory method, however, due to its simplicity and its reliability is to use a ring sample supplied with primary and secondary windings placed in a calorimeter and to measure the losses by simple calorimeter methods. The inductions may be measured by means of an electro-static voltmeter connected to the secondary winding[39].

Recommendations—Due to its simplicity, its reproducibility and almost universal adoption, the Epstein apparatus as standardized by the A. S. T. M. is probably the most satisfactory method to use for acceptance tests for electrical sheets. By adopting the substitution method (2-c) outlined above, simple commercial apparatus may be used and the results will be entirely satisfactory for acceptance tests. If, however, research work is to be done, this simple apparatus will hardly suffice, especially if results at various inductions and frequencies are required. In that case a variable speed generator is required, preferably with a harmonic booster and a means of measuring the form-factor.

The Lloyd apparatus, while used at the Bureau of Standards, has not met with wide favor elsewhere, due probably to the complication of making corrections for the corner pieces.

The saving in material by the use of the Robinson apparatus is probably more than offset by the greater complication of the apparatus, decreased accuracy, the effect of shearing on the narrow samples and the fact that material from at least two sheets of steel should be used to give a good average for the lot.

For experimental work at high inductions, the

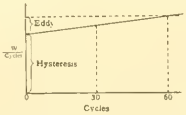


FIG. 26—SEPARATION OF LOSSES

three-phase ring method, when used with a sensitive polyphase wattmeter, may be recommended.

For radio frequency work the differential calorimeter method can be recommended as being simple and giving reproducible reliable results.

SEPARATION OF LOSSES

The hysteresis and eddy current losses may be separated by the following methods[40].

1—Two-frequency method.
2—Two-form-factor method.
3—Two-induction method.
4—Alternating-current and ballistic method.

1—The well-known two-frequency method consists in obtaining alternating-current core-loss data at two or more frequencies, say 30 and 60 cycles for instance, dividing the results for a given induction by the frequency, and plotting the watts per cycle against the frequency(as shown in Fig. 26). The intercept on the vertical axis gives the hysteresis loss in Watts per cycle, as indicated, and the eddy current loss as indicated in watts per cycle for 60 cycles. This method may be applied to rotating machines, as well as Epstein and similar samples.

2—The two form-factor method consists in obtaining the core loss for two different form-factors with the average volts (and therefore the hysteresis loss) held constant. The difference in the two losses is equal to the change in the eddy loss which, of course is proportional to the square of the r.m.s. voltages, thus making it possible to determine the eddy losses.

3—By measuring the losses at two inductions and assuming that the hysteresis loss varies as the 1.6 power of the induction and the eddy losses at the square, it is possible to determine W_h and W_e from wo simultaneous equations. If one induction is one half the other then,

$$W_h = \frac{4W_1 - W_2}{0.97} \qquad \ldots (14)$$

4—If desired, an alternating-current test may be made on a sample, then the hysteresis loss determined by a permeameter or some ballistic means. This hysteresis loss multiplied by the frequency of the alternating-current test gives the hysteresis loss, from which and the total alternating-current loss, the eddy current loss may be determined.

The two frequency method is the simplest and is applicable to rotating machines and polyphase circuits. Care must be taken, however, to insure that the form-factor is the same for the different frequencies. The two form-factor method is perhaps the more accurate where suitable means are available for altering the form-factor. The two induction method is not as accurate as the two previous methods since there are often quite appreciable departures from the 1.6 power and square laws. The fourth method is of use only in special cases.

[21]Ewing. 138.

[22]B. O. Pierce, *Proceedings American Academy of Arts & Science,* Vol. 44. p. 354, 1909.

[23]Campbell & Dye. *Journal of I. E. E.* Vol. 54, p. 35, 1915.

[24]W. L. Cheney. Magnetic Testing of Straight Rods in Intense Fields. *Bureau of Standards Scientific Paper No.* 361.

[25]Kennelley. *Trans. A. I. E. E.* Vol. 8, p. 485, 1891.

[26]J. D. Ball. Some Notes on Magnetization Curves. *G. E. Review,* Jan. 1915, p. 31.

[27]Sanford and Cheney. Variations of Residual Induction and Coercive Force with Magnetizing Force. *Bureau of Standards Scientific Paper No.* 384

[28]Rice & McCollum. Ballistic Dynamometer as an Instrument for Testing Iron. *Physical Review—Vol.* 29, p. 132. 1909

[29]Ewing. p. 380.

[30]Kennelley and Alger. Magnetic Flux Distribution in Annular Steel Laminae. *Proc. A. I. E. E.* Dec. 1917, p. 1113.

[31]M. G. Lloyd. Effect of Wave Form upon the Iron Losses in Transformers. *Bureau of Standards Scientific Paper No.* 88.

[32]M. G. Lloyd. The Dependence of Hysteresis upon Wave Form. *Bureau of Standards Scientific Paper No.* 106.

[33]M. G. Lloyd & J. S. Fisher. Apparatus for the Determination of the Form of a Wave of Magnetic Flux. *Bureau of Standards Scientific Paper No.* 87.

[34]Chubb & Spooner. Effect of Direction of Grain on the Magnetic Properties of Silicon Sheet Steel. THE ELECTRIC JOURNAL—Vol. 13, p. 303. 1916.

[35]Spooner. Determining Iron Losses of Sheet Samples. *Electrical World*—Vol. 77, p. 91. Jan. 8, 1921.

[36]Lloyd and Fisher. The Testing of Transformer Steel. *Bureau of Standards Scientific Paper No.* 109.

[37]L. T. Robinson. Commercial Testing of Sheet Iron for Hysteresis Loss. *Proc. A. I. E. E.* Vol. 30, p. 741, 1911.

[38]Nicholson. *Proc. I. E. E.* Vol. 53, Jan. 1915.

[39]Spooner. High Frequency Iron Losses. JOURNAL *A. I. E. E.* Sept. 1920, p. 809.

[40]Spooner. Magnetic Properties of Sheet Steel. THE ELECTRIC JOURNAL. Vol. XIV, p. 90, March 1917.

Commutator Insulation Failures

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COMMUTATOR insulation failures are very annoying and aggravating. In a large plant these troubles usually do not come singly. One motor after another may fail. When the motor is again placed in service after being repaired the trouble may occur again after a period of operation that is entirely too short. Sometimes there is an epidemic of commutator trouble. The reason is that where certain conditions exist, there will be trouble and, as these causes often extend to hundreds of motors in the same plant, many motors will be affected. There are probably more of these failures on motors operating in or around steel plants than on all other applications combined. A failure in the commutator may be the cause of short-circuits in the armature winding which may necessitate complete rewinding.

A well built commutator, properly maintained, will give little operating trouble. Commutator failures are usually the result of the following general conditions:—

1—Carelessness and neglect,

2—Lack of understanding of the principles underlying the construction and operation of the motor,

3—Indifference of the operator, who is more interested in output than maintenance expense,

4—Improper construction of rebuilt commutators.

Practically all commutator insulation failures are caused by one or a combination of the following causes:—

1—Rough burrs on the bars or clamping rings.

2—Excessive voltage between bars due to turns being cut out of armature, etc.

3—Carbon dust or other conducting materials under the bars.

4—Oil between the bars or at the edge of the bars, causing pitting which eventually burns through the mica V ring.

5—Mill dust, carbon dust, copper slivers, moisture and oil on the exposed parts of the V rings, causing insulation failures, unless precautions are taken to protect them and keep them fairly clean.

Usually, the fundamental causes are due either to oil or to conducting dust, although there are many contributing factors. The oil may have come from the bearings, if there are no oil throwers on the shaft, or it may have been spilled on the commutator accidentally when oiling the bearings, or oil or some other lubricant may have been applied to the surface of the commutator bars by the operator with the object of improving commutation.

Mill dust or iron ore dust, or the carbon dust from the brushes, if allowed to collect in some pocket or crevice, bridges across the mica between two bars and causes failures. Dust usually accumulates on the exposed insulation at the ends of the bars and even works its way under the bars. Small slivers of copper caused when turning or machining the copper, or when undercutting the commutator mica segments, may be the cause of trouble.

COMMUTATOR MATERIALS AND CONSTRUCTION

The kind of mica and copper used, and especially the dimensions and fits of these materials with each other have more to do with commutator insulation failures than is generally realized. When it is considered that a variation of 0.001 inch on each mica strip or on each commutator bar makes a 0.031 inch difference in diameter for a commutator with 100 bars and may be double that if the variation occurs with both the bars and mica, it is evident that precautions are necessary to build a good commutator. The copper bar grooves, the mica V-ring, and the V of the iron bush all require the same diameter at the point of the V. It is also vital that they have the same degree of taper. When these parts do not fit perfectly with each other and are then clamped together, there will be small crevices which may be observed only by making a very careful examination. Although small to the eye, these crevices will be large enough to permit fine particles of dust to find their way under the bars.

The copper from which the bars are made should be hard drawn and not soft copper which has been machined to shape. Soft copper does not have the good wearing quality of hard copper. It is also liable to bend up at the ends and allow small crevices, as well as to cause chattering of the brushes.

The built up mica should have the best compound and the proper amount of it for sticking the mica laminations together. Some compounds that are used do not stick the mica to the bars, which will increase the probability of loose mica.

The writer recently had occasion to examine some commutators made by a concern which "remakes commutators" and furnishes parts for many crane motors and mill motors. These commutators were made with the following modifications from the original construction. The mica segments were 0.031 inch thick instead of 0.025 inch, which would increase the chance of high mica. The compound used for sticking the mica laminations together would not stick to the copper bars. Soft copper machined to shape was used for the bars instead of hard-drawn copper punched with a die. The machined V's were not accurate, and one end was 1/16 inch smaller in diameter at the gauge point than it should have been. This shows the importance of having all repair parts properly made from accurate drawings, and of having suitable dies and tools.

When assembling the commutator, conducting material may have been deposited in the assembled

bars or perhaps be partly buried in mica V-rings. When turning commutators there may be small slivers which have burred over. If the commutators have been undercut, the cut at the end of the mica segment may have been pulled instead of cut clean, which makes a frayed corner.

EFFECT OF COPPER SLIVERS, CARBON DUST, MILL DUST OR ORE DUST

Heating of bars is probably due to bridging over the mica segments between the bars by small particles of copper, carbon or other conducting dust. This trouble may occur on either the front or rear end of the commutator or on the parts under the bars. If the rear end of the commutator is not fully protected, by packing it solid with insulation, there will probably be more trouble there than on the front end, because conducting dust which settles on the armature, cannot be removed from the rear V-ring.

EFFECT OF OIL

Pitting between bars is probably traceable to the presence of oil, grease, or other lubricant on the commutator. This trouble from oil or lubricants usually affects the front end only. If the V-rings become filled with oil they become soft and gummy. The capillary attraction of the oil draws in the carbon dust from the brushes and also other conducting particles. Although oil itself is a good insulator, it adds no insulating qualities between two bars if there is a particle of conducting material bridging across the mica strip, even if the oil surrounds the particle of dust. Oil has two very harmful effects when in or on a commutator. The first is that the oil dissolves the compound used between the mica splittings. The second is that an arc breaks up the oil into carbon, a gas and a liquid which makes the path more susceptible to a second discharge. This is so important that at least one large manufacturer has a metal plate prominently fastened directly above the commutator, stating "Caution—Use no lubricant on commutator".

VARNISH ON COMMUTATORS

A smooth, hard, glossy, varnish surface on the end of the bars and on the insulation which protects the projecting part of the mica V-rings, gives excellent protection. However, care must be taken in applying it, for liquid varnish in the commutator where it will not dry is harmful. Liquid varnish does not dissolve the bond in the mica, but it does act much the same as oil when subjected to sparking.

REMEDIES

1—Obtain copper bars, mica segments and mica V-rings of the best material and absolutely correct dimensions. Be sure the copper, the mica V, and the iron bush fit accurately. If the commutators are to be undercut, make a clean cut at the end of the bars so as not to leave a frayed corner on the mica strip. Do not undercut a commutator until after it has been trued up by turning, as the turning drags the copper more or less.

2—Make sure that there is no dirt in the copper V or on the mica V when assembling. Sandpaper lightly the part of the mica V which rests against the bars immediately before putting it in place, so as to remove any particles of dirt that may have accumulated on it, and do not lay it down on anything that is not absolutely clean. Clean out the copper V immediately before inserting the mica V.

3—If the commutator is of the solid neck type, the rear end can be effectually protected by filling the space from the mica V-ring to the bottom lead with insulation. The top should also be protected by placing an insulating hood over the winding which extends over the leads and onto the commutator neck.

4—If the motor is totally enclosed keep the handhole covers on at all times.

5—Apply over the projecting part of the mica V-ring three turns of surgical tape which has been treated in varnish. Sew all three layers so as to join the start and the finish. Apply about five coats of varnish. Each coat of varnish must be thoroughly dry before applying the next coat. A baking varnish is preferable to an air drying varnish. Apply this same insulation to the rear end as well as the front end if the space from the mica V-ring to the bottom lead is not built up solid with other insulation in such a manner as to seal it. Apply this insulation so that there will be no pockets formed next to the bars, and also at the end of the mica V so that nothing can enter between the mica ring and the iron bush. This will make a smooth, hard, glossy surface. Also apply five coats of varnish to the ends of the bars.

6—Keep all oil, grease or other lubricant away from the commutator.

7—Do not allow any varnish or shellac to get into the commutator under the bars where it would not dry.

8—Brush off the dust from the insulation at the ends of the bars occasionally.

Adherence to the above suggestions at all times will reduce commutator insulation failures to a minimum.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

DECEMBER 1921

General Information on Grid Resistance Design for the Operating Man

Probably no one piece of apparatus is more essential to the successful operation of a motor car or locomotive than the starting and accelerating resistor. This one item alone causes higher maintenance charges than any other individual piece of apparatus.

THE NECESSITY FOR A STARTING AND ACCELERATING RESISTOR

The series motor used in railway work is normally a low resistance machine. Should it therefore be connected directly to the 600 volt trolley, enormous currents would flow which would be limited only by the small amount of motor resistance and that of the circuit connections. This current in addition to the serious effects on the mechanical and electrical parts of the motor, would cause a very severe starting jolt on the car.

WHY THE CAPACITY OF THE RESISTOR IS BASED ON CURRENTS LARGER THAN THE CONTINUOUS CAPACITY REQUIRED OF THE MOTOR

With the various materials available for the construction of grid resistors, cast iron is chosen as the best for flexibility, ease of manufacture, and application to a particular design. Casting the material in units makes it possible to use a great number of combinations in the same assembly and still maintain a structure which is satisfactory in appearance and size. Although cast iron in itself is bulky, it gives the most resistance and radiation for the same space factor. Should it be assumed that the capacity of the resistor is to be sufficient to carry the total current continuously it would be impossible, in a great many cases, to place the resistor on the car. This is due to the fact that with a given mass, only a definite amount of radiation can be obtained under a given mounting and hence ventilation conditions.

In calculating the total continuous capacity required of the motor for a particular service run, the time that the power is on constitutes a large percentage of the total time. With the starting resistor the time that the power is on constitutes a small percentage of the total time. The average heating current for the resistor is therefore considerably less than that of the motor. As the capacity of a conductor is a question of radiation and as radiation is based on surface exposed to air currents, the smaller the average heating curent, the smaller would be the conductor required. The conductor in this case being the grid resistor, the smaller the current the smaller the total resistor will be. In a few words then, the resistor size is kept down by working a small amount of material very hard for a short space of time.

HIGH SPOTS IN THE DESIGN OF A GRID RESISTOR

In the design of grid resistors the following elements enter into and affect the final result.

1—Car weight, unloaded,
2—Wheel diameter,
3—Gear ratio,
4—Motor characteristics, } The motor curve as made by the manufacturer includes these items.
5—Average line voltage,
6—Type of control
7—Number of motors,
8—Motor resistance.

The two factors to be considered are, resistance value and capacity. Taking them in the order in which they are calculated, the resistance is determined by the amount of current required, on the first notch, to give the necessary starting tractive effort to start the car as fast as possible without undue discomfort to the passengers. Experience has shown that for average city and interurban service 135 to 165 pounds tractive effort per ton will give a good start.

As a hypothetical case we will assume 30 tons as the weight of the car with a starting tractive effort of 140 pounds per ton. The total tractive effort required to accelerate the car will be 4200 pounds. It has already been decided that the service in which this car will operate requires four 50 hp. ventilated motors. The tractive effort required per motor is therefore 4200 ÷ 4 or 1050 pounds. The motor curve for the conditions involved gives a current of 54 amperes.

If the resistance is figured for this current, according to Ohm's law, due to the inductance of the motors and the main circuit connections, the current per motor will not actually reach 54 amperes until a short interval after the main circuit to the motors has been closed. Therefore, the tractive effort will not be sufficient to give the desired start. To take care of this loss in tractive or starting effort, an inductance factor of 0.75 is used. To obtain the proper current value the above current of 54 amperes is divided by the inductance factor 0.75, which gives a current of 72 amperes.

With four motors and series parallel control, the motors will be connected in two groups of two motors in parallel with the two groups in series. The current in the resistor for the first notch will therefore be 2 × 72 or 144 amperes. Assuming the average voltage to be 550 volts, the total resistance required will be 550 divided by 144 or 3.82 ohms. The resistance of the motor at 75 degrees, is 0.745 ohm. The resistance of the grids and the connections between the motor and the trolley should be the difference between 3.82 ohms and the motor rsistance or 3.075 ohms. An approximate method of obtaining the resistance value is to divide the average voltage by the hour current rating of the motor.

The next step in the design is to divide this resistance into the proper steps to obtain smooth acceleration. There are various methods of doing this which are based on empirical figures obtained from a careful study of the subject and the actual design of a great number of resistors.* These values, however, vary to some extent, depending on all the conditions involved, so that in each individual case there is a certain amount of cut and try before the final design is completed. It is sufficient, therefore, to say that the resistance values should be so proportioned as to give a systematic progression in cutting out. On motor cars, approximately 40 percent of the total resistance, including that of the motors, is cut out on the second notch. On locomotives this figure is considerably lower, and will vary to a greater extent than on motor cars, due to a wider range of conditions. The remaining series notches are then divided in proportionate steps, keeping in mind that the values in the series position will in most cases be the same as those used in the parallel position. Some manipulation is required in a great many cases to obtain the proper notching in both the series and the parallel positions.

CURRENT CAPACITY OF THE GRID RESISTOR

As stated above it is not necessary to allow a capacity in the grid resistance equivalent to the continuous capacity required of the motor. A still further reduction in capacity is possible, due to the fact that only a small part of the total resistance is in circuit during the complete acceleration. It is therefore evident that the capacity of any notch need be only sufficient for the proper radiation of the heat generated while that particular section of the resistance is in the circuit. The same experience which has taught the proper arrangement of the resistance steps also teaches to allow the proper current capacities for the various notches. In the majority of cases, this has proven to be between the values of 35 percent minimum and 85 percent maximum of the total continuous current. In other words for the first notch we would allow the lower figure and for the last notch the higher. The intermediate notches are divided proportionately. Consideration should be given however, to the various combinations where the steps are used in parallel, in which case allowance should be made.

APPLYING STANDARD GRIDS TO THE CALCULATED DESIGN

As the resistance values and the capacities of the several steps are known it is only necessary to pick out the proper grids to fit the design. It will be found that the design must be modified to fit the resistance of the grids set by the capacities required. In some cases the resistance will be increased and in others decreased, so that the total resistance will remain about the same. When choosing the poper capacity for the grid the calculated capacity required must be the same as that listed for the commercial grid. The current value listed is the continuous capacity of the grid.

HARRY R. MEYER.

*See article on "Design of D. C. Accelerating Resistors" by L. J. Hibbard, in the Journal for Oct., 1916, p. 508.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. Questions concerning general engineering theory or practice and questions regarding apparatus or materials desired for particular needs will be answered. Specific data regarding design or redesign of individual pieces of apparatus cannot be supplied through this department.

To receive prompt attention a self-addressed, stamped envelope should accompany each query. All data necessary for a complete understanding of the problem should be furnished. A personal reply is mailed to each questioner as soon as the necessary information is available; however, as each queston is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting a reply.

2062—CONNECTIONS FOR POWER-FACTOR METER—Kindly explain the action of a power-factor meter, also show a diagram of the internal and external connections for three-phase systems.
J. J. B. (ILL.)

The power-factor indicator is an instrument designed to give a direct reading, at any instant of the power-factor in a circuit or system of circuits, as well as to indicate whether the current is leading or lagging. The power-factor of a single-phase circuit may be calculated from the reading of an ammeter, voltmeter and wattmeter. The power-factor of a balanced three-phase circuit can also be calculated directly from the readings of two wattmeters used to measure the power, knowing the voltage and current in the circuit. A direct reading power-factor indicator, however, is usually to be preferred for station purposes, as such a meter gives the power-factor directly and also indicates whether the current is leading or lagging. Under certain conditions it is more convenient to obtain a direct measure of reactive (wattless) power supplied to a circuit; only a wattmeter can be used for this purpose. The moving vane type of power-factor meter, contains a movable soft iron vane which

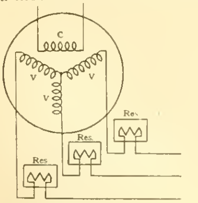


FIG. 2062—(a).

in the polyphase instrument, is magnetized through a stationary coil carrying a current in phase with the current of one phase of the circuit. There is one stationary shunt coil for each phase, the arrangement being such as to produce a rotating field. The moving vane thus takes up a position in which the direction of the flux produced in it by the current coil when at a maximum is coincident with the direction of the resultant flux due to the voltage coils. In the three-phase instrument, three voltage coils placed 120 degrees apart are used; in the two-phase meter, two voltage coils at 90 degrees are used. In the single-phase type, the iron vane is energized by a stationary coil placed in phase with the current of the line, while the rotating field is produced the same as in the two-phase instrument by means of only two potential coils approximately 90 degrees apart; one of which, however, is connected to the line through a non-inductive resistance, and the other through a reactance. For the purpose of damping the instrument an aluminum disc operates in the field of two permanent magnets. In Fig. (a) three stationary energizing coils or rotating field coils are shown connected in star for three-phase connection. The single current coil *C* which energizes the moving vane has both leads brought out to the top of the instrument. This diagram gives a general idea of the internal connections.
H. P. S.

2063—Z-CONNECTION OF CURRENT TRANSFORMERS—The system shown in Fig. (a) is a three-phase, four-wire, 4000/2300 volt system with grounded neutral. Will the Z-connection of current transformers give absolute protection on all phases, using only two relays, or will it be necessary to install three relays and connect the current transformers in star. A. M. N. (OHIO.)

Three current transformers arranged according to the Z-connection, together with two relays, give absolute protection against overload on either a three-phase, four-wire system or a three-phase, three-wire system with grounded neutral. The principal disadvantage of this scheme for

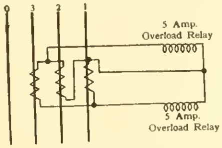
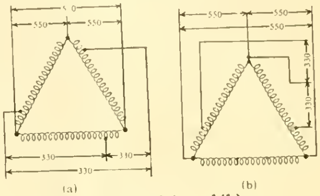


FIG. 2063—(a).

straight overload protection is the somewhat more complicated wiring. This may be an important factor when meters and other instruments are operated from the same set of current transformers. R. C. S.

2064—STARTING INDUCTION MOTORS ON 60 PERCENT VOLTAGE—An installation consisting of three 200 hp. 550 volt induction motors is supplied from a bank of transformers consisting of three 150 kv-a, single-phase transformers connected delta on the secondary. In an installation of this kind, where all the motors are alike and consequently having the same starting qualities i.e., they start on a 60 percent tap or 330 volts, would it not be feasible and also practical to eliminate the autotransformer starting equipment for each motor and have taps brought out from the transformer for starting? This arrangement would only require three-pole double-throw switches. Do transformers acting in this dual capacity have to be of special design? If so please explain. Is my sketch correct?
R. H. N. L. (B. C.)

The three motors can be started by using low-voltage taps on the transformers which supply the motors with power. The transformers would be of special design in that the windings would have to have one or more special taps brought out. If there were frequent and long heavy starts, the windings might have to have heavier bushings. The elimination of the autostarters would eliminate all protective features, such as overload and no-voltage release protection and quick transfer from low to high voltage. Some added apparatus would be necessary to give the overload and low-voltage protection. A three-pole, double-throw knife switch would not be safe for the interruption of the energy of 550 volt, 250 hp. motors. Hand operated oil



FIGS. 2064—(a) and (b).

switches or magnetic contactors would be more suitable. The auto-starters use oil immersed switches. The scheme of connections as shown in Fig. (a) is all right. However, a better connection is shown in Fig. (b) which requires that only two of the three transformers be special.
W. C. G.

2065—CONNECTIONS FOR SYNCHRONOSCOPE—Kindly explain action of synchronoscope when synchronizing two alternators, also show diagram of connections for three-phase systems.
J. J. B. (ILL.)

The inductor-type synchronoscope as shown in Fig. (a) has two windings. The upper winding is connected directly to the incoming machine while the lower winding is connected to the running machine through a resistance. The running winding consists of two parts, one of which is connected in series with a non-inductive resistance and the other with an inductive resistance in order to produce a

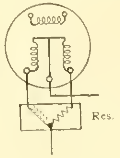


FIG. 2065 (a).

rotating field necessary for the operating elements. The pointer can rotate freely in either direction and is so arranged that when the frequency of the incoming machine is lower than that of the running machine it rotates in the direction indicated by *slow* on the dial, or if the frequency of the incoming machine is higher than that of the running machine it will rotate in the opposite direction, indicated by *fast*. on the dial. When the frequencies of both machines are the same, the pointer will stop at some position around the dial, depending on the

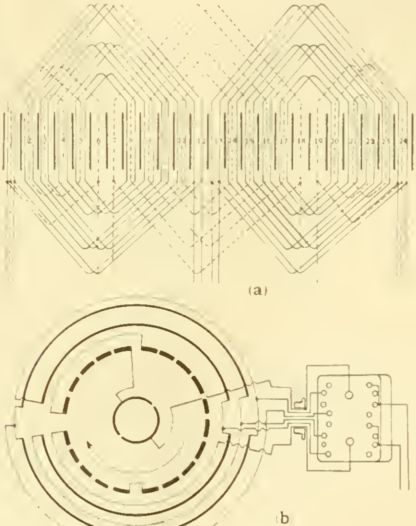
angle by which the voltage of the incoming machine is out of phase. The instrument is so designed that when the two machines are in synchronism the pointer will be in a vertical position upward, which is the only position marked on the dial. Thus the instrument indicates when the frequencies of the two machines are the same and also when they are exactly in synchronism. An excellent article on "Synchronizing with a Synchronoscope" by J. C. Group was published in the JOURNAL for Dec. 1920 p. 567.

M. M. B.

2066—TWO-SPEED MOTOR—Please explain how the two and four-pole change is made on a 1/6 hp, single-phase, 60 cycle, 110 volts, 1700-3400 r. p. m. motor. A. H. K. (CALIF.)

The 1/6 hp, single-phase, 60 cycle, 110 volt, 1700-3400 r. p. m. motor is provided with a special main winding and a starting winding, so that by means of a pole changing switch the two speeds mentioned can be obtained. The main winding is wound with two coils as in a two pole motor except there are two wires in parallel and eight leads are brought out for connection to the pole changing switch, as shown in Fig. (a). The starting winding consists of one coil with two-pole pitch or throw and two coils with four-pole pitch or throw, six leads being brought out from these three coils for connection to the pole changing switch, as in Fig. (a). The leads from the main and starting windings are connected to the pole changing switch as per Fig. (b). With the motor leads at the left of the pole changing switch in Fig. (b) numbered from top to bottom, connecting lead 1 to one side of the line and lead 3 to the other gives the four-pole connection or the consequent pole arrangement. By connecting leads 2 and 4 across the line the two pole connection will be obtained. The pole changing switch is so arranged that the starting winding is connected across the line with the switch in either the two or four pole position. The two solid outside coils in Fig. (a) in each pole indicate the two coils which are wound in parallel as mentioned above. The operation of the motor as a two-pole or four-pole motor is the same as any series and consequent pole arrangement. The starting winding, however, functions along slightly different lines and an analysis of the flux from the various starting winding coils for the two connections of the switch will indicate that its operation is the same as a two-pole motor with one coil missing in the one case and a four-pole motor with two coils missing in the other case.

C. A. M. W.



FIGS. 2066—(a) and (b).

2067—SHORT CIRCUITED COIL—In a five hp, three-phase, 60 cycle, 220 volt, 1750 r. p. m. induction motor, star connected, we have a coil which I think is short-circuited within itself because I disconnected the particular coil and there is no ground or short-circuit with another coil, making the test with a test lamp. So I cut out that coil and tried the motor but it still gets hot on that particular coil. I then short-circuited the two ends of the coil and it heats just the same. It seems to heat up with it in circuit or out of circuit and I have not been able to locate the trouble. H. I. I. (HAWAII)

This short-circuited coil is cutting the primary flux just the same as any of the other coils, and acts as the secondary of a transformer, with the other motor coils acting as the primary. It is necessary to clear the short-circuit in this coil, either by opening all the turns, preferably at the back end of the coil and carefully insulating the ends of each turn, or else by removing this coil completely. The motor will never operate satisfactorily as long as there is a short-circuited coil where it can cut the motor flux, even though this coil be electrically disconnected from the circuit. C. R. R.

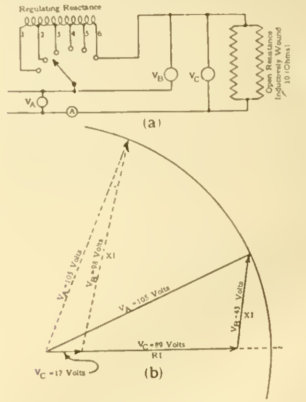
2068—VOLTAGE DROP ACROSS REACTANCE AND RESISTANCE—Kindly explain the following phenomena. Fig. (a) shows the connections of a bake oven I constructed. As it is used on alternating-current, I made a reactance coil with taps at different points in the winding to regulate the heat. This coil has a closed magnetic core. V_A, V_B, and V_C, were made by one and the same voltmeter, the meter being moved to these different positions to get the various readings.

Reactance Switch in position	Amps.	V_A	V_B Reac.	V_C Res.	Total V_B & V_C
1	1.5	105	98	17	115
2	2.15	105	93	36	129
3	3.1	105	83	55	138
4	4.05	105	68	71	139
5	5.0	105	43	89	132
6	6.0	104	0	104	104

Now, the question is, why is the sum of V_B and V_C higher than the voltage V_A accross the line? Can this oven resistance act like a condenser?

N. J. V. (CAL.)

Your oven resistance does not act like a condenser. The sum of the voltages measured by the voltmeter at points *B* and *C* is greater than the voltage across the line measured by voltmeter at *A* because the line voltage is not the arithmetical sum of the two voltages but



FIGS. 2068—(a) and (b).

is the vector sum of the voltage drop across the resistance and reactance coils, as shown with solid lines in the vector diagram for position 5 Fig. (b). If the resistance was wound non-inductively and the reactance coil was without resistance then the vector *RI* or drop across the resistance would be exactly 90 degrees out of phase with the *XI* vector representing reactance drop. Since there is considerable resistance in the reactance coil and a certain reactance drop across the inductively wound resistance the vectors *XI* and *RI* are not exactly 90 degrees out of phase. The rectors representing V_A, V_B and V_C, in Fig. (b), are shown dotted for reactance switch in position 1. M. M. B.

2069—SPECIAL INSULATION FOR MOTORS—I believe it is customary to furnish special insulation on motors for Panama, India and other tropical countries in order to make these motors serviceable under extreme heat and moisture conditions. Kindly advise what this special insulation would consist of in case of a 100 hp, 440 volt, alternating-current motor.

A. K. (WISC.)

The coils are made up of double cotton covered conductors and to the exact shape for winding into the slots. They are then thoroughly treated in a moisture resisting compound. The slot portion of the coil is wrapped with a wrapper composed of mica built up on paper. The first and last coil of each group where the phases change are taped on the ends with treated tape, half overlapped. All coils are then taped over all with a layer of cotton tape half overlapped on the ends, but not lapped on the slot portion of the coil. The coils are then thoroughly treated in a moisture resisting compound. Paraffined fish paper is placed into the slots into which the coils are placed. The completely wound winding is then dipped in a moisture resisting varnish two or more times, draining and drying it in a heater after each dipping. J. L. R.

2070—TRANSMISSION LINE CONSTRUCTION—Are there any good reasons for not adopting a method of increasing the capacitv of an existing 6600 volt transmission line two miles long by stringing a second 300 000 circ. mil. cable below the present one, which is supported by a suspension disk; provided of course that all other factors entering the problem, such as strength of towers, wire spacing, ultimate tensile strength of suspension and strain insulators, etc. would allow such practice. M. G. A. (ARIZ).

The addition of the 300 000 cir. mil. cable will be satisfactory and will increase the capacity of the existing line from 8700 to 14 500 kv-a approximately, based on a temperature rise of from 10 to 15 degrees C. The division of current between the two cables is such that the smaller cable will carry 48 percent of the

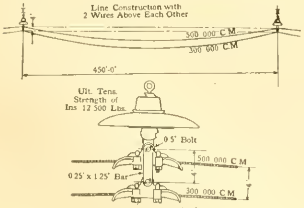


FIG. 2070 (a)

total current. The rated carrying capacity of a 500 000 circ. mil. cable is 755 amperes for a 10 degree C. temperature rise and for a 300 000 circ. mil. cable, 515 amperes. Of the total current of 1275 amperes the smaller cable must carry 48 percent or 610 amperes, which is in excess of the value given above and corresponds to a temperature rise of approximately 15 degrees C. The larger cable carrying 665 amperes would have a temperature rise of 8 degrees C. The calculation of the division of current in the two cables is as follows:—

$$E_1 = R_1 I_1 + j\,\omega\,(L_1 I_1 + M_{12} I_2 - M_{1A} I_A) \qquad (1)$$

$$E_2 = R_2 I_2 + j\,\omega\,(L_2 I_2 + M_{21} I_1 - M_{2A} I_A) \qquad (2)$$

where E_1 and E_2 = Voltage drop in the cables.
R_1 and R_2 = Resistance of cables.
I_1 and I_2 = Current in cables.
L_1 and L_2 = Self-inductance of each cable.
M_{12} and M_{21} = Mutual Inductance between two cables.
M_{1A} and M_{2A} = Mutual Inductance between each cable and the return circuit.
E_2 must equal E_1

Subtracting (2) from (1)

$$O = R_1 I_1 - R_2 I_2 + j\,\omega\,[L_1 I_1 - L_2 I_2 + M_{12}(I_2 - I_1)] \qquad (3)$$

(M_{1A} is assumed to be equal to M_{2A} which is a very close approximation)

$$I_1 [R_1 + j\,\omega\,(L_1 - M_{12})] = I_2 \{R_2 + j\,\omega\,(L_2 - M_{12})\} \qquad (4)$$

Then,

$$\frac{I_1}{I_2} = \frac{R_2 + j\,\omega\,(L_2 - M_{12})}{R_1 + j\,\omega\,(L_1 - M_{12})} \qquad (5)$$

The self-inductance of each cable may be calculated from Equation (6) which is the same as equation (95), page 151, Bureau of Standards Bulletin 169.

$$L = 2l\left(\log_e \frac{2l}{R_g} - \tfrac{3}{4}\right) \qquad (6)$$

Where L = Inductance in centimeters (Multiplying by 10^{-9} to reduce to henrys)
l = Length of conductor in centimeters.
R_g = Geometric mean radius of conductor
R_g = 0.7788r where r = radius of conductor

The mutual inductance between conductors is calculated from equation (7), which is the same as equation (99), page 151 Bureau of Standards Bulletin 169.

$$M = 2l\left(\log_e \frac{2l}{d} - 1 + \frac{d}{l}\right) \qquad (7)$$

Where M = inductance in centimeters (Multiplying by 10^{-9} to reduce to henrys).
d = distance between conductors in centimeters.

From (6) and (7)

$$L - M = 2l\left(\log_e \frac{2l}{R_g} - \tfrac{3}{4}\right) - 2l\left(\log_e \frac{2l}{d} - 1 + \frac{d}{l}\right) \qquad (8)$$

$$= 2l\left(\log_e \frac{2l\,d}{R_g\,2l} + \tfrac{1}{4} - \frac{d}{l}\right) \qquad (9)$$

$$= 2l\left(\log_e \frac{d}{R_g} + \tfrac{1}{4}\right) \text{ since } \frac{d}{l} \text{ is negligible} \qquad (10)$$

Length of line (2 miles) = 321 869 centimeters.

$$L_1 - M_{12} = 643\,738\left(\log_e \frac{25.4}{0.622} + \tfrac{1}{4}\right) = 2\,860\,000$$

=0.00286 henry; hence X = 1.078 ohms, assuming that the average spacing of conductors is 10 inches.

$$L_2 - M_{12} = 643\,738\left(\log_e \frac{25.4}{0.805} + \tfrac{1}{4}\right) = 2\,700\,000$$

= .00270 henry; hence X = 1.02 ohms.

Substituting in equation (5),—

$$\frac{I_1}{I_2} = \frac{0.234 + j\,1.02}{0.392 + j\,1.078}$$

The percent of total current flowing in the smaller conductor is then:—

$$\frac{I_1 \times 100}{I_1 + I_2} = \frac{0.234 + j\,1.02}{0.626 + j\,2.098} \times 100 = \frac{2.286 + j0.148}{4.8} \times 100 = \frac{229}{4.80} = 47.7\%$$

W. E. D.

2071—RE. QUESTION 1980—Relative to question No. 1980, please explain how the capacity of the transformer secondary is figured to be 350 kv-a. I realize this 350 kv-a is 220 volts, three-phase, feeding from the middle points of the three 200 kv-a transformers. W. M. E. (ILL.)

Fig. (a) indicates the loading on the secondary of the bank. The load current of any phase has two parallel paths through the transformers. For instance, phase AB has one path, A, 1, B and another path A, 3, C, 2, B. The first mentioned path is one-half the length of the second path; therefore, the current will divide between these two circuits in the ratio 1 : 2. Let I_P represent the current that passes any point between B and A in the secondary windings. Then, with an equal load on all phases,

$I_P = \tfrac{2}{3}\, I_{AB} - \tfrac{1}{3}\, I_{BC} - \tfrac{1}{3}\, I_{CA}$ .... (1)

If the secondary load is balanced and $I_{AB} = I$, then

$I_{BC} = (-\tfrac{1}{2} - j\,0.866)\, I$

$I_{CA} = (-\tfrac{1}{2} + j\,0.866)\, I$

Substituting the values for I_{BC} and I_{CA} in equation (1), it will be found that $I_P = I$, that is, the current in the secondary of the transformers is equal to the 220 volt phase current. The normal current in the transformer secondary is $\frac{200\,000}{440}$ = 445 amperes, therefore, the 220 volt load that gives normal current in the transformer secondary = 445 × 220 × 3 = 300 kv-a, balanced three-phase. The transformer primary supplying 300 kv-a will, however, be only one-half loaded, therefore the loss, and consequently the temperature will be below normal. With

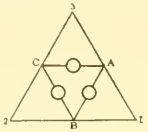


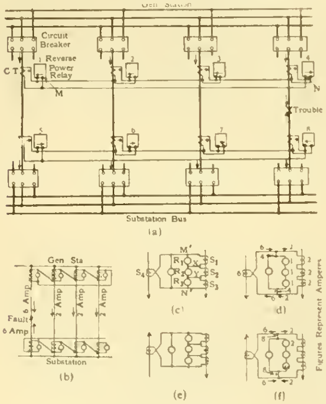
FIG. 2071 (a)

equal amounts of copper in the primary and secondary the sum of the losses will be normal when the transformer is delivering 380 kv-a, which gives 63 percent load on the primary and 127 percent load on the secondary. But normal temperature would be exceeded at 380 kv-a as the total loss is normal, but the secondary temperature gradient would be high on account of it being overloaded. In order to compensate for this the load must be reduced. It will be found that 350-kv-a, which gives 117 percent load on secondary and 58 percent load on primary or 86 percent of normal copper losses, will give approximately normal temperature rise in the secondary of the transformer. J. F. P.

2072—CROSS-CONNECTED RELAY SYSTEM—Fig. (a) is a diagram of a cross-connected relay system described in an article by Mr. L. N. Crichton in the JOURNAL. The arrows indicate the direction of flow of current in the transformers, relays etc., with a short-circuit on feeder D as shown. As the arrows show, the reverse power relays are tripping out their respective circuit breakers on both ends of the feeder in trouble. I can readily see where there is a reversal of power flow causing relay 8 on the sub-station end of the defective feeder, to trip, but fail to understand what is causing the circuit breaker on the station end of the feeder to trip, as there is apparently no reversal of power flow here. Can you tell me why the current flow in relays 1, 2 and 3 is the reverse of

that in 4, 5, 6 and 7 when the current in their respective transformers, flows the same way. H. R. L. (PENNA.)

In this relay connection or in any other method of using directional relays, it is not necessary to have a reversal of power flowing in order to cause a relay to trip. Directional relays intended for line protection are so connected in the circuit that they will operate when the power is flowing away from the bus-bars which may be the normal direction. In the cross-connected scheme there is no current in the relays under normal conditions. When the current is the same in all the lines, the secondary current flows around the loop through the transformers and does not go through the relays due to their impedance. When one line carries more current than the others, the excess secondary current will be forced through the relays, part of it through relay No. 4, and the remainder through relays 1, 2 and 3 in series. That the direction of the arrows on relays 1, 2 and 3 is correct is evident if you keep in mind that the terminal N on relay 4 is at a higher potential than the other terminal and that terminal N on relay 4 is at the same potential as terminal M on



FIGS. 2072—(a) to (f).

relay 1. A convenient method of analyzing the circuit is shown in Figs. (b), (c), (d), (e) and f. Assume that the fault draws six amperes, from the line in which it occurs, and that each of the other lines feed into it, two amperes. Since the current is the same in all good lines, the current transformers can be represented as being placed in series on one line, as shown in Fig. (c). Now the current from the current transformer S_1 through the jumper X into the relay R_1 is just balanced by the current in the opposite direction in transformer S_2. In other words, there is no current flowing in the jumpers X and Y and consequently they may be omitted (for purpose of analysis) as shown in Fig. (d). It is evident that the current which will flow through the relays is the difference between the current from the transformers in the good lines and the transformer in the bad line. The current which flows between M' and N' through the relays divides inversely as the impedance of the two circuits. If it is also borne in mind that the potential is the same between points M' and N', no matter through which of the four paths the current may be traced, the solution of any part of the circuit can easily be obtained. The conditions at the substation end of the lines are similarly shown in Figs. (e) and (f). L. N. C.

2073—TESTING TRANSFORMER—We have a 220 watt air-cooled potential transformer, 60 cycles, 2 200 volts primary, 122 volts secondary with a middle tap. Please advise if we can use it for testing insulation of coils, twin wires, etc., at about 4 000 volts or less with the connection shown in Fig. (a). We have put 110 volts across the middle tap and one outside wire without any trouble for a short length of time (about 5 minutes). How can I calculate the testing voltage from the incoming value—that is, within 110 volts of the true voltage. What voltage should I get (approximately) on the high voltage side, with 110 volts connected as shown? R. A. B. (MASS.)

Since the transformer in question has rated voltages of 2 200 high voltage and 122 low voltage—the ratio of transformation must be 18 to 1. Using one-half of the low voltage winding will give a ratio of 36 to 1, consequently 110 volts applied to the middle tap and one outside wire of the low voltage winding will give 110×36=3960 volts on the high voltage side. It must be recognized, however, that by applying

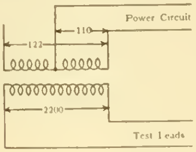


FIG. 2073—(a)

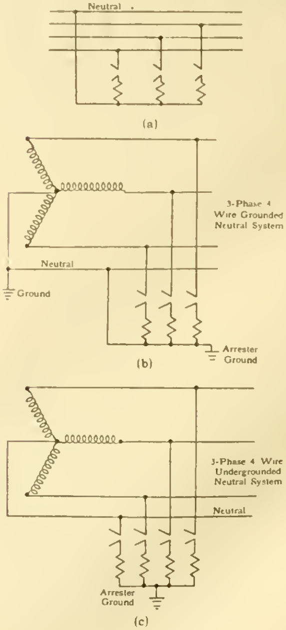
110 volts to one-half of the low voltage winding, the insulation of the transformer will be subjected to a voltage strain, eighty percent above normal. Furthermore 180 percent of normal voltage applied to one-half of the low voltage winding, may cause an excessive value of exciting current, sufficient to overheat the winding. The plan is not to be recommended. However, it might be used in an emergency for very short time service. E. I. C.

2074—UNSATISFACTORY OPERATION OF WATTHOUR METER—We are having trouble with a 2 200 volt, 200 ampere, 60 cycle, Watthour Meter, operating on a three-phase, 2 200 volt circuit connected in the conventional way through potential and current transformers. The meter is used to record the entire station output. On one phase the meter will rotate very slowly—and seem to hesitate at some point in the revolution. In some tests it reverses or seems to do so while on the other phase it operates correctly. In an attempt to correct the trouble the meter was first sent to the factory, tested and calibrated and O. K'ed by them. A set of two potential and two current transformers of the portable type were installed in place of the switchboard type but this did not correct the trouble. Two meters of the same type are operating satisfactorily on out going circuits on the same switchboard. C. H. B. (NEW JERSEY)

A polyphase meter, properly calibrated and correctly connected will behave as you have described, at certain conditions of changing power-factor. Briefly, stated the torque on one element of a polyphase meter is zero at 50 percent power-factor. At power-factors below 50 percent the torque is negative on the same element, while at power-factors above 50 percent the torque is positive. Therefore, as the power-factor changed from values below 50 percent to values above 50 percent the direction of rotation of the disk would change from negative to positive, if the other element is disconnected. For detail data see METERMANS HANDBOOK, pp. 167 to 175; METER CODE, pp. 86 to 93; "A Method of Determining the Correctness of Polyphase Wattmeter Connections", by W. B. Kouwenhoven, A. I. E. E. Feb. 1916; and "A Study of Three-Phase Wattmeter Connections" by C. R. Riker, in the JOURNAL for Sept. 1912, p. 765. A. R. R.

2075—CONNECTION FOR LIGHTNING ARRESTERS—We have installed some lightning arresters as shown in Fig. (a). Would you call that a delta or star connection? A. A. (MEXICO)

We would call the connection in Fig. (a), a star connection. To be effective the arresters in Fig. (a) should have a ground connection. If the system has the neutral grounded the ground connection should be attached



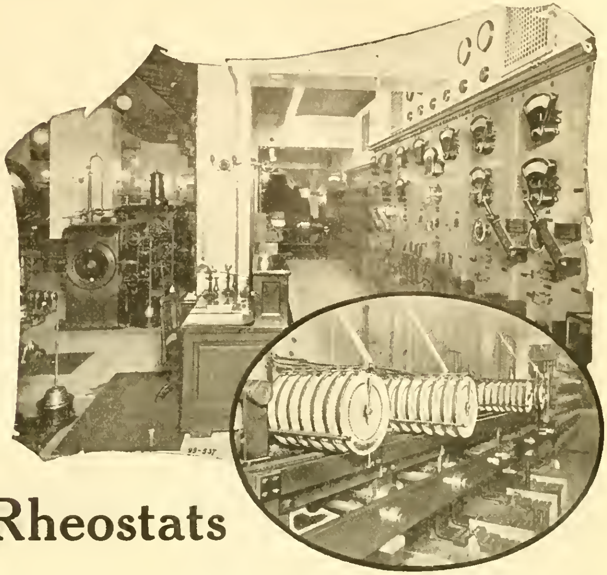
FIGS. 2075—(a), (b) and (c)

to the common connection of the arresters shown in Fig. (b). If the neutral of the system is not grounded a fourth arrester should be placed between the fourth lead and the ground connection. The fourth arrester in Fig. (c) may be good for either 100 percent or 58 percent of the line voltage. G. C. D.

An 18-Year Old Vitrohm Set

WARD LEONARD
VITREOUS ENAMELLED RESISTOR UNIT
8000 Ohms
VITROHM

Here in the power plant of the Metropolitan Building, New York, is a striking example of the real sturdiness of



Vitrohm Field Rheostats

Note how these units are almost duplicates of our present-day product. Look back at your motor or transformer built 18 years ago—compare their 1903 crudeness with the present-day refinements—then consider the originality, the correct engineering knowledge that enabled H. Ward Leonard (the founder of our company) to design and build Vitrohm units 25 years ago.

This Metropolitan job of four generators equipped with Vitrohm Rheostats has been operating satisfactorily daily for each and every day of the eighteen years. It is this kind of service that has caused the growth of Ward Leonard to its present size.

The construction of Ward Leonard Vitrohm Field Rheostats is fundamentally the same today as in 1903. Solid grids, with Vitrohm, vitreous enamelled insulation enveloping and protecting the resistance element against corrosion or oxidation, which would destroy ordinary resistance wire when heated and cooled in service.

If you have resistance problems in connection with plant operation or manufacture of electrical apparatus, our experts will gladly assist in their solution.

We will gladly send you a free sample Vitrohm Resistor Unit (vitreous enamelled, just like Vitrohm Rheostats) so you can see and test for yourself the properties of Vitrohm.

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Mount Vernon, New York

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William Miller Tompkins—Philadelphia
Walter P. Ambos Co.—Cleveland
Wm. G. Merowit, Buffalo
Sperry & Bittner, Pittsburgh
Intermountain Sales Co., Denver

Westburg Engineering Co.—Chicago
Electric Material Co.—San Francisco
Electric Material Co.—Los Angeles
Electrical Specialties Co.—Detroit
Geo. W. Pieksen—St. Louis
Wm. Geipel & Co., London, England

THE HARRINGTON ROCKING CABLEWAY FOR MATERIAL HANDLING

One of the problems of central stations, as well as steel mills and other manufacturing concerns is the economical handling of material such as coal, ashes, etc. In cases where a permanent storage space is desired the expense of steel structures for the material handling devices may be justified. However, the Railway & Industrial Engineering Company of Greensburg, Penna., have recently developed a conveying system that seems to have all the merits of previous systems without involving heavy expense in structural materials. The Harrington Rocking Cableway, as illustrated, makes use of swinging end supports for the cable and these supports are counterweighted so that the

FIG. 1—AN INSTALLATION OF THE HARRINGTON ROCKING CABLEWAY

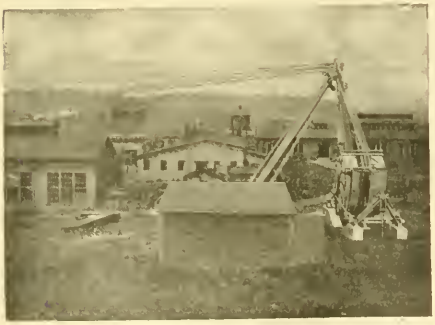


FIG. 2—VIEW OF TOWER SHOWING COUNTERWEIGHT IN ROCKED POSITION

entire system is balanced. With a supporting tower at each end of the storage area the overhead cable may be moved to any desired alinement, so that the material can be discharged at any determined position in the storage area. The foundations required are simple and are only at the end of the storage area. The cableway can be built to serve an area approximately one and one-half times wider than the height of the towers themselves. This arrangement is entirely independent of the contour of the ground in the area to be served and the towers may be at different elevations. There is a tower at each end of the space of the A-frame type and each tower is counterweighted in such a way that, after the towers reach an inclination of about 45 degrees further inclination is prevented. Suitable arrangements of cables and carriers have been developed so that the loads of material may be dumped at any desired location. Arrangements are made so that the towers rock in unison and power for hoisting is supplied by electric motor or other drive. The cableway can load to and from cars on tracks running either parallel to the side of the pile or at an angle across the pile. Only one operator is necessary, so that the handling expense is very low and the operator can be located either at the hoist or at any other convenient point where he can view the operations. It is claimed that the cableway speed allows the making of two or three trips of the bucket to one trip of other types of machines such as bridge cranes, etc. In one installation with a span of 220 feet, the average time for a complete cycle, which consists of loading, hoisting and moving the bucket diagonally across the entire area, unloading and returning to the loading point, was 50 seconds. The speed of the carriage along the main cable is given as 800 feet per minute and the hoisting speed of the bucket 120 feet per minute. This development should warrant the very thorough consideration of those having to analyze such problems, as the designers have gotten entirely away from previous methods used in material handling.

A NEW AUTOMATIC STARTER FOR D. C. MOTORS

A great many installations of automatic starters for D. C. motors of 10 H. P. or less are in relatively remote or inaccessible places where operating conditions are by no means the best. Places where such starters are installed may be damp or subject to fumes which promote corrosion, and through lack of attention it frequently happens that the equipment which the motor drives becomes clogged, jammed or blocked in some manner which will prevent the motor from starting when the automatic starter functions. The result of adverse atmospheric conditions is the deterioration of the equipment, especially of the starting resistance. The result of the load being blocked is the burning of the starting resistance, the motor or both, and so there has been an extensive demand created for a starter which would withstand these adverse conditions of installation and operation. To meet this demand The Automatic Reclosing Circuit Breaker Company of Columbus, Ohio, has developed and placed on the market its Type "SS" Automatic D. C. Motor Starter. This starter is designed for 250 or 500 volt service in capacities of 3, 5, 7½, and 10 hp. It is of the counter-e. m. f. type with one step of resistance which is automatically cut out when the motor comes up to speed. This resistance is made of nickel and chromium alloy wire, the very highest grade material available for withstanding corrosion, and is of such value that it limits the starting current to the full-load current of the motor and of sufficient capacity to carry this current indefinitely. These elements of design give the type "SS" starter the special and important charcteristics of protecting the motor, should it fail to start its load, against burning out of either motor or starter, and insuring the very longest life under adverse atmospheric conditions.

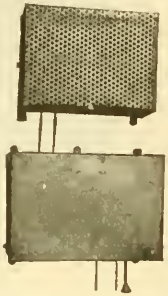


FIG. 1—TYPE "SS" STARTER WITH COVER CLOSED

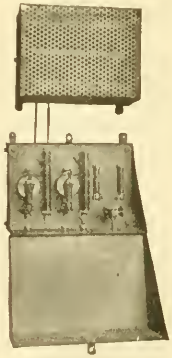


FIG. 2—TYPE "SS" STARTER WITH COVER OPEN

This starter is applicable where the starting torque required does not exceed the full torque of the motor and, in a very large percentage of installations of motors of this capacity, it is found that the starting torque required, nowhere nearly equals the full-load torque of the motor. Especially is this true of motors driving pumps, blowers and rotating apparatus not having excessive static or starting friction, or where the load comes on as or after the motor comes up to speed. As shown in Fig. 1, the type "SS" starter comprises two units; one the starting resistance mounted and completely housed in a perforated sheet iron box. Connections between the starting panel and resistance are made at the time of installation. The cover and the box housing the panel are provided with lugs for receiving a padlock so that the panel may be secured against exposure of any live parts or molestation by unauthorized persons. Fig. 1 shows the box with the cover closed and Fig. 2 with the cover open. The construction of all details of this starter is rigid and substantial and all current carrying parts of ample capacity. The guiding thought has been to produce a reliable and durable starter without sacrifices in either the amount or quality of material or workmanship.

NEW BOOKS

"Space and Time in Contemporary Physics"—Morris Schlick—87 pages—6 by 9 inches. Published by the Oxford University Press. For sale by The Electric Journal. Price $2.50.

Sir Isaac Newton's discussion of the gravitational relations between heavenly bodies are highly mathematical and are familiar only to astronomers and advanced physicists. Nevertheless every high school student has come to understand the fundamental principles upon which Newton's work was based. It now appears that Newton's work, while accurate, was incomplete and a broader general theory of physics, which includes all of Newton's theories as a particular limited case of the general theory, has been announced by Albert Einstein. This new theory has aroused profound interest in scientific circles and has been brilliantly confirmed by astronomical observations. It is highly mathematical and, in its entirety, must ever remain the sole property of astronomers and advanced physicists. As with Newton's theories, however, the general principles upon which it is based can be understood by the layman, once he adapts his mental concepts to an entirely new viewpoint. Schlick's book on "Space and Time" gives, as comprehensively as is possible with only simple mathematics, an explanation of the general and special theories of relativity, and a general discussion of the application of Einstein's work to modern physics, concluding with a discussion of the finitude of the universe and the relations of the new physics to philosophy, which is somewhat startling to one who has not yet adapted his mind to the new ideas. C. R. R.

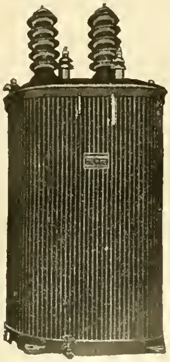
"Practical Electricity" —Terrell Croft, 646 pages, 548 illustrations, Published by McGraw-Hill Book Company, Price $3.00.

This is the second edition of this work originally published in 1917. It covers substantially the same ground as the first edition, that is, it aims to give the fundamental facts and theories relating to electricity and its application, in a simple style so that even the readers who only understand arithmetic will be able to read understandingly. As in other text by this author much attention has been given to the matter of illustrations to aid readers in getting a clearer understanding of principles. For a book of this kind it would seem that the author has rather gone to extremes in introducing discussions on such terms as elastance, darafs ("farads spelled backwards") etc. Even discussions on resonance and similar expressions would seem to confuse rather than aid the practical electrician who really has little use for such terms in his everyday work. Of course, it is easy enough for one to skip such sections in a book but, for a work of the extremely practical type, it would seem better for the author to play safe by not attempting to show off his entire box of tricks. The book as a whole, of course, is excellent and the above comments cover only minor details.

"Service at Cost Plans"—Harlow C. Clark—315 pages. Published by American Electric Railway Association, New York City. Price $2.50.

Of all the local utilities, the street railways have manifestly suffered most at the hands of city governments. For years street railways were the football of local politicians. The rising tide of prices only served to crystalize the embarrassing situation some had already reached and towards which others were rapidly drifting. As Mr. Clark explains, the street railway is next in order to sewage and water works systems in the matter of importance to urban life. Therefore, it is essential that the obstacles to the solution of the local transportation problem be removed. Municipal ownership is invariably wasteful and, therefore, creates extra burdens for the tax payers. Cost-plus plans are next in line in eliminating the undesirable antagonism and this book is devoted to a thorough discussion of the history of such methods of regulation. In many of the more recent cases, broader provisions have been inserted in the agreements. This work is so arranged as to present clearly these facts and should, therefore, serve a most useful purpose in aiding the utilities to secure not only fair treatment but sufficent consideration to stir private initiative to accomplish greater public service and convenience. E. D. D.

MOLONEY TRANSFORMERS



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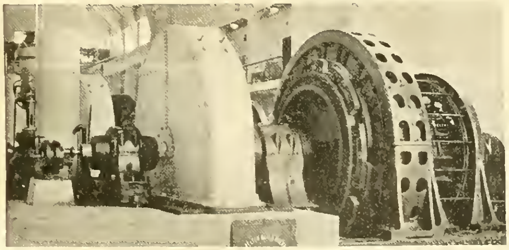

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